PLANTS OF THE PAST

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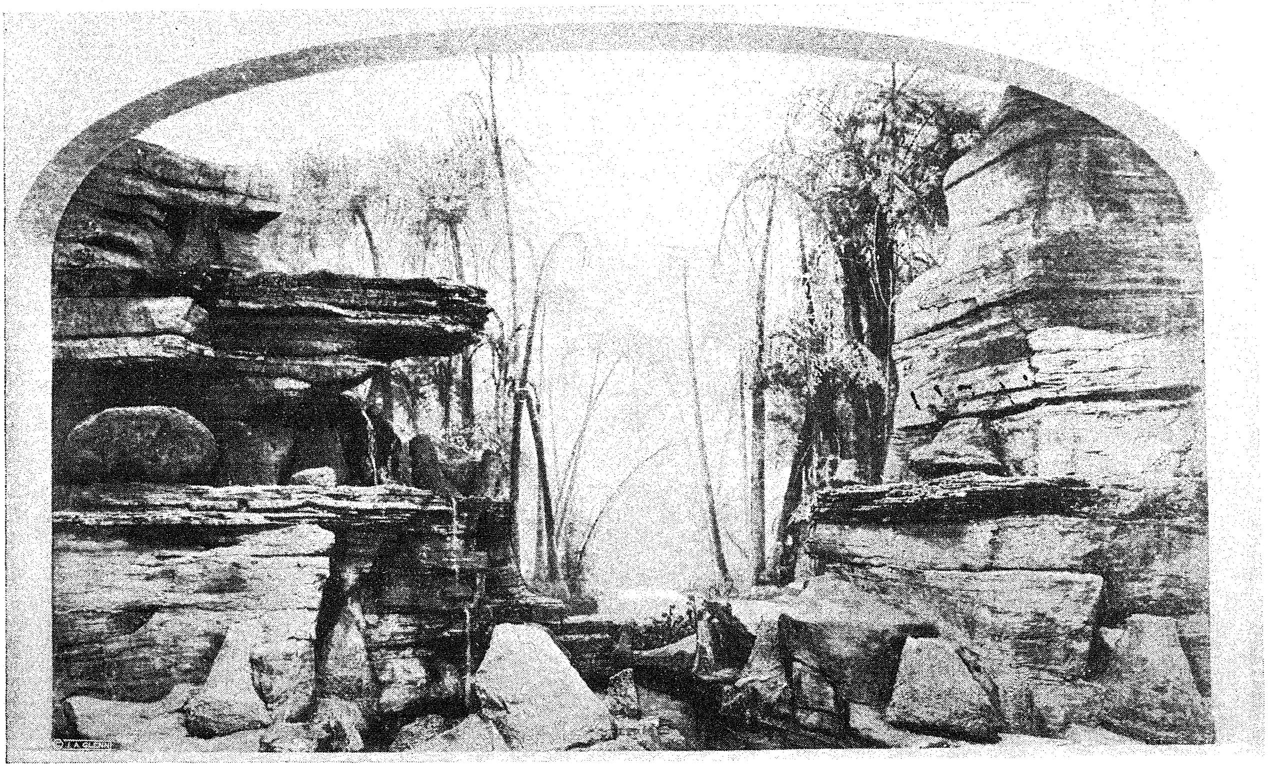

Oldest known fossil forest of seed ferns (*Eospermatopteris textilis*) from the Devonian, Gilboa, New York. Group preserved in State Museum, Albany. Actual fossil trunks in foreground, painted restoration in background. Kindness Miss Goldring.

Plants of the Past

A POPULAR ACCOUNT OF FOSSIL PLANTS

BY

FRANK HALL KNOWLTON, PH.D., SC.D.

GEOLOGIST, UNITED STATES GEOLOGICAL SURVEY
CUSTODIAN MESOZOIC PLANTS
UNITED STATES NATIONAL MUSEUM

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To my wife

PREFACE

THIS book was undertaken at the suggestion of a friend in one of the leading universities, who gave assurance that a need for it was shown by numerous requests made by students and teachers (especially those directing nature study) and by seekers of general cultural information. These requests indicated a demand for a work of moderate size, written in non-technical language, that should set forth the salient facts regarding the plants that have clothed the earth from the time when life first appeared down to the present. Such a book I have attempted to prepare. It was not designed primarily as a text-book of paleobotany, though it can be made the basis of an elementary course, to be supplemented and extended by the instructor to any extent desired. It was planned rather as a narrative—a reading book—which should present an account, in simple language, of the more important plants that have lived in the distant past, many of them millions of years ago. This account has been supplemented by illustrations showing the form and features of specimens of the plants, as well as by restorations that show how the plants must have appeared when they were living.

Many of the figures have been made from photographs of specimens in the United States National Museum, but as it was not always possible to procure satisfactory illustrative material from this source, the published works of other writers on fossil plants have been drawn upon. The source of all borrowed figures is given in the explanatory legend under each figure, and grateful acknowledgement is hereby made to all who have permitted the use of such pictures. A number of original photographs have been supplied by Dr. C. D. Walcott, Dr. George R. Wieland, Dr. John W. Gruner, and Miss Winifred Goldring. Most of the photographs of specimens and copies of published pictures have been made by Dr. Chas. E. Resser, of the United States National Museum, and Miss Frances Wieser, the accomplished paleontologic artist of the United States Geological Survey, has been especially helpful with advice and assistance in preparing the illustrations for publication.

PREFACE

In deciding on a method of treatment two plans were considered. The first plan is to begin with living plants and follow them back through the geologic ages to their point of origin—a plan that has the obvious advantage of passing gradually from the known and familiar to the less known and the less familiar. The other and more logical plan is to begin with the first known forms of plant life and trace their evolution, step by step in time, as they actually developed. This is the plan followed in this book.

In addition to the chapters treating of the floras of the successive geologic ages several chapters have been added that expand or interpret certain phases of the subject, such as the influence of plants on the evolution of animals, the effects of human action in the operations of nature, the problem of plant evolution, the manner in which coal is formed, and the value of the study of fossil plants.

I am indebted to many friends and colleagues for assistance and advice, particularly to Professor Ben F. Howell, of Princeton University, who has offered invaluable suggestions. Dr. Arthur Hollick, of the New York Botanical Garden, has read the entire manuscript and suggested valuable additions. Dr. James W. Gidley, of the United States National Museum, and Dr. Edwin Kirk, of the United States Geological Survey, have read certain chapters and have contributed valuable suggestions. Mr. George M. Wood, former editor of the publications of the United States Geological Survey, has also read much of the manuscript and has suggested certain literary changes and improvements. To my wife, Rena G. Knowlton, I am indebted for helpful advice and criticism, especially for suggestions bearing on clarity of statement. Mrs. Wilbert L. Merriken has been particularly generous in helping to prepare the manuscript. To all these collaborators, as well as to the many others who have helped me in any way, I extend my sincere thanks.

F. H. KNOWLTON

U.S. National Museum,
May 1, 1926

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Introduction

HOW PLANTS BECOME FOSSILS

FOSSIL plants are the remains or impressions of plants that lived and died long ago and were buried and preserved in the rocks of the earth's crust. It gives one a thrill to break open a piece of solid rock or a lump of clay and find in it the remains of a plant that has not seen the light of day for a million years. It is fascinating, too, to think that the next blow of the hammer may reveal a plant, or a part of a plant, the like of which has never before been seen by mortal eye, or one that will help us to understand some step in the long pathway that plants have followed from their beginning in the remote and shadowy past down to their present state as seen in those that clothe our fields and glades and hills.

Such a piece of rock is shown in *Figure* 1. The blow that split

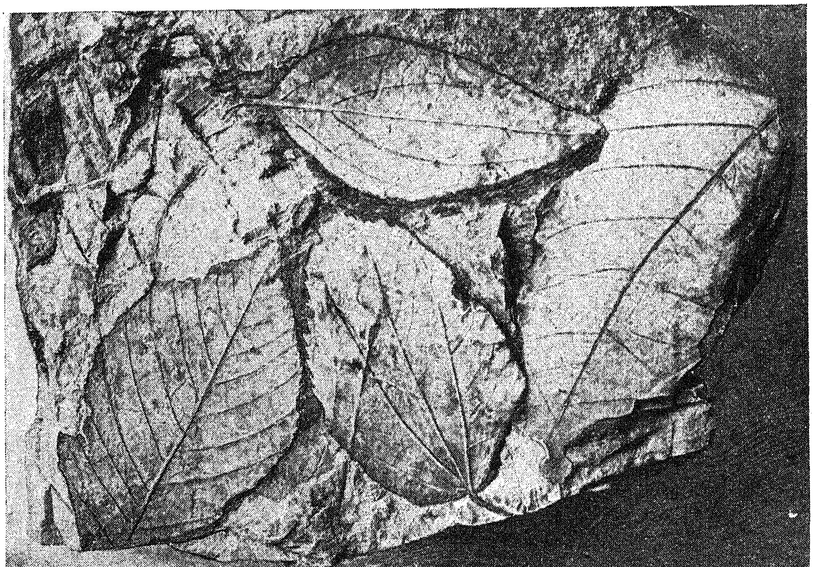


FIG. 1. Leaves disclosed on splitting a piece of rock from the Eocene of the State of Washington. Perhaps three million years old.

it open brought to view a mass of impressions of leaves so perfectly preserved that it is hard to believe they were not taken from a living tree; yet these impressions are probably not less than three million years old. *Figure* 2 shows a fragment of a delicate fern that may have lived a hundred million years ago, yet the

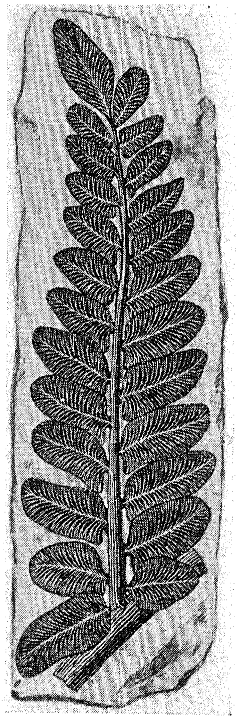


FIG. 2. Leaf of a Carboniferous fern, perhaps a hundred million years old.

outline of the leaf and the form of each delicate vein are as perfect as if the fragment had been plucked from a living plant. These figures suggest some of the thrills that may await the hunter of fossil plants, whose work it is to aid in deciphering the pages of long-past earth history—to find the story that we may read of plants that lived thousands or millions of years ago.

It must not be presumed, however, that every piece of rock will show a plant when broken open; such a presumption would be very far from the truth. Fossil plants are found only or mainly

in sedimentary rocks—that is, in rocks or deposits that have been laid down in or by water—and all the conditions for preservation must be so nicely adjusted between the plant and its environment that it is really surprising to find so many plants preserved. A plant must have been covered by mud or sand before it decayed, and after it was so covered it must have remained undisturbed until the mud or sand in which it was embedded had hardened into rock.

The word *fossil*, as it was originally used, meant anything dug up out of the earth, but it now has a more definite, a technical meaning; it is applied to any organic body, plant or animal, that is so buried in solid rock or in any earthy deposit that it may be preserved indefinitely. Strictly speaking this definition would include any leaf, seed, cone, or other part of a plant that happened to be covered by the mud or sand laid down by a freshet of yesterday, provided it was so deeply buried that it would not decay and disappear; but in ordinary everyday usage the phrase "*a fossil plant*" means one that is as old at least as the Great Ice Age; whereas one that has been buried since that time is spoken of as recent, as they are mainly species still living.

Plants or parts of plants may be preserved as fossils in several different ways. The commonest and most familiar way is known as preservation by impression or inclusion. In this form of preservation a part of a plant, usually some small or thin organ, such as a leaf, branchlet, flower, or seed, is covered with or inclosed in clay, sand, or limy ooze or mud that became limestone, very much as a living leaf may be inclosed between layers of wax or modelling clay. When the layers of clay or wax are pulled apart it is found that the leaf has left its exact impression on them. In some fossil plants the substance of the leaf or other part preserved has been changed to a thin layer or film of coaly matter, which shows no cell structure and may be blown away as dust when the rock is split open, so that only the impression of the outline and the veins is left. Only in rare specimens is the substance of the leaf, together with a part of the original cell structure, so perfectly preserved that the fossil can be taken up unbroken from the rock and mounted between pieces of glass to form what may be called a natural herbarium specimen. A very perfect ginkgo leaf of this kind, taken from Miocene clay near Spokane, Washington,

is shown in *Figure* 3. In nearly every specimen, however, all trace of the plant substance has disappeared; we find only the impression. The clearness and fidelity of this impression depends

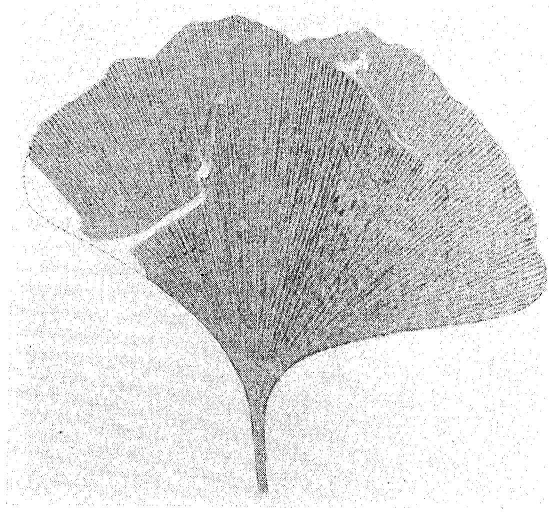


FIG. 3. Leaf of maidenhair tree (*Ginkgo*) taken entire from Miocene clay at Spokane, Washington.

largely upon the nature of the rock in which it is preserved. If the rock is a fine-grained sandstone or limestone, or a fine-grained clay, every detail of outline and nervation may be as perfectly preserved as it would be in a living leaf. Many such impressions are shown on later pages.

A large part of our knowledge of the plants of the past has been gained from a study of plant impressions, which are especially abundant in beds of clay and shale that are associated with coal, particularly in the beds that lie just above the coal. In the roof of a mine of Tertiary coal near Trinidad, Colorado, there is a mat of huge palm leaves, some of them five feet across. In the roof of mines that work Carboniferous coal it is not rare to find masses of fern leaves five or six feet long, made up of hundreds of leaflets, suggesting in size and habit some of our living tree ferns.

Plants are also preserved in amber, a fossil resin, usually a product of some coniferous tree, such as a pine or a spruce. When

this resin was soft the plants fell or were blown into it, and, being sealed up from the air, they have been so perfectly preserved that every detail of some specimens can be studied as well as if they were obtained from living plants. *Figure* 4 shows a piece of Baltic amber enclosing an exquisite little flower of the camphor tree.

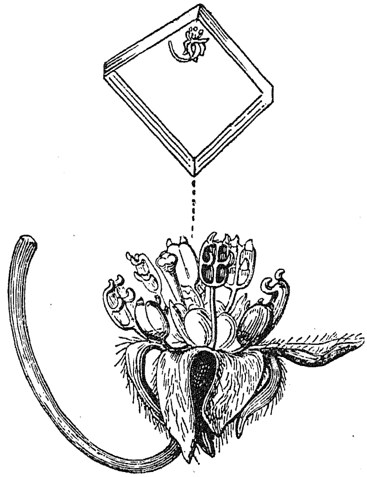


FIG. 4. Flower of camphor-tree (*Cinnamomum*) in Baltic amber. Upper figure natural size; lower figure much enlarged. After Göppert and Menge.

Incrustations of plants by the silica or lime in the water of warm or hot springs are rather common. Any object, such as a pine cone, if placed in such water for a short time, may be completely inclosed by a layer of mineral matter; or a mat of leaves may be thus cemented together, and although the substance of the leaves may be removed later, their forms are perfectly preserved. Several years ago some incrusted fragments of a large, heavily veined leaf that must have been a foot long and six inches wide, were sent to Washington from the Yellowstone National Park, where the hot waters of the springs and geysers hold a large amount of silica in solution. This incrusted vegetation was very puzzling, for no plant that even remotely resembles it is now growing in that region. Some years later it was found that a kind of tobacco used there came wrapped in a natural leaf of the tobacco plant, and fragments of such a leaf that had fallen into the water had become completely coated with silica.

The other principal means by which plants are preserved as fossils is known as infiltration. The plant so preserved, most commonly a trunk of a tree or a piece of wood, though it may be stem, leaves, seeds, or in fact any part of a plant, falls into or is carried into water that holds in solution a large amount of silica, lime, magnesia, or other mineral matter. The water penetrates the plant, and as the plant decays the mineral matter takes its place, molecule by molecule, until finally the organic matter is completely replaced by the mineral matter. The replacement may be so complete that not only the cellular structure but the most delicate markings on the cells are exquisitely reproduced in stone, and the whole may then be cut into thin sections and studied under the microscope just as if the sections had been cut from a living plant. The contents of the cells, including resin, delicate threads of fungi, even the minute bacteria that cause decay, have in some specimens been caught and replaced by the mineral.

Plants that are preserved by infiltration are of the utmost value in a study of the vegetation of the past, and they are eagerly hunted for and highly prized when they are found. A large part of our most accurate knowledge concerning ancient plants has been supplied by materials preserved in this way.

Fossil wood, or petrified wood, which is found in many parts of the world, represents plants of many geological ages. It usually occurs as isolated logs, stumps, or smaller fragments, but here and there so much of it is found in one place that it is called a fossil forest, such as is seen in Chalcedony Park, Arizona; in the Napa Valley, California; near Cairo, Egypt; and especially in the Yellowstone National Park. In most of these forests the trees were lying down when they were fossilized. In the Arizona forest hundreds of acres are thickly strewn with prostrate logs, some of them eight feet in diameter and 125 feet long. In the fossil forests of the Yellowstone National Park, however, hundreds of trunks stand upright, exactly in the position in which they grew thousands of years ago. Most of these trunks wear away nearly as fast as the rocks in which they are buried, but a few of them stand twenty or thirty feet high, and the huge roots go down into solid rock. All of them lost their branches when they were buried by a shower of volcanic ashes and mud. *Figure 5* shows the trunk of a fossilized sequoia twenty-six and one-half feet in

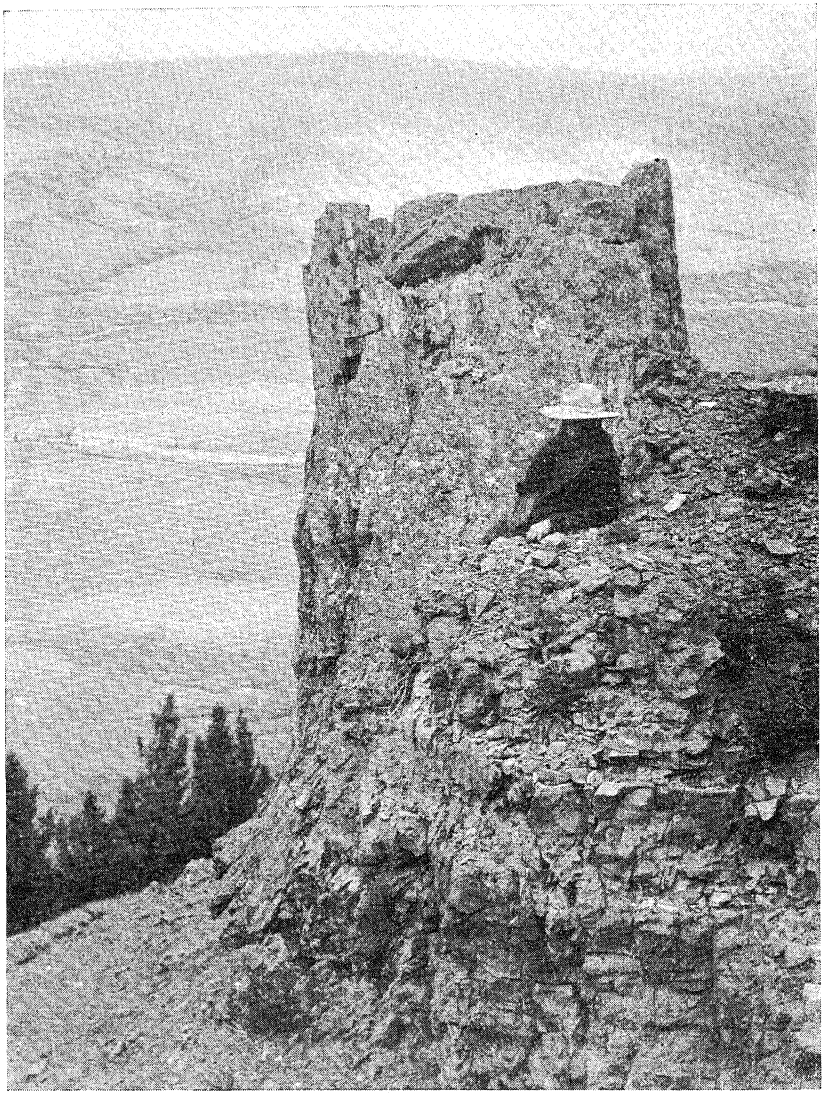


FIG. 5. Upright trunk of *Sequoia* 26½ feet in circumference, in Yellowstone National Park.

circumference and twelve feet high, and *Figure* 6 shows the perfectly preserved structure in a section of the wood of this tree.

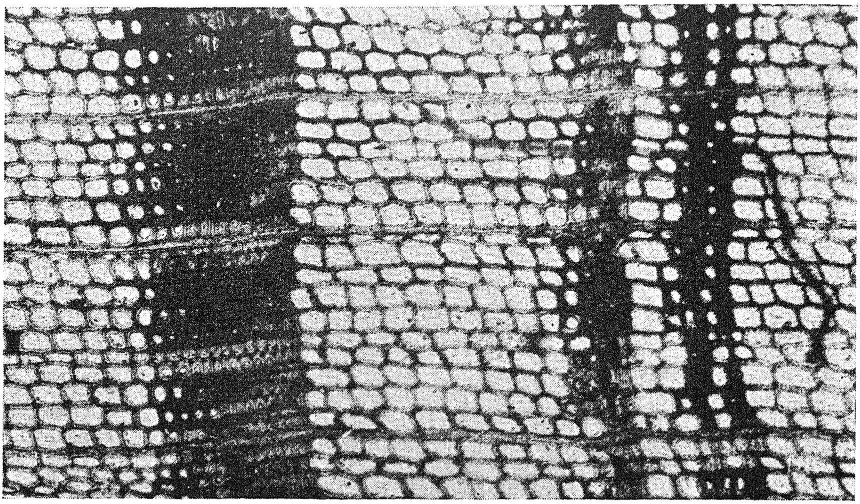


FIG. 6. Transverse section of wood of fossil *Sequoia*, showing growth rings, from Yellowstone National Park. Enlarged about 90 diameters.

In some beds of lignite, which is a deposit representing one of the steps in the formation of coal, it is possible to make out the trunks or parts of the trunks of trees, and the cellular structure of some of them is so well preserved that it can be studied, though it is usually very much crushed and distorted. A few cases are on record where a log has been changed to lignite at one end, which was embedded in clay, and replaced by silica at the other end, which was embedded in sand.

Some remarkable remains of plants preserved by infiltration of calcium carbonate (limestone) are known as "coal balls." These balls, which are about the size of a man's fist, are found in coal, especially in mines in England, and France; rarely in the United States. They consist of a miscellaneous mass of fragments of plants, such as stems, leaves of ferns, cones, and spore cases, many of them remarkably well preserved. Some of our most valuable and most reliable knowledge of the flora of Carboniferous time has been gained by a study of these "coal balls."

The remains of plants are preserved also by casts or molds.

Some bulky part of a plant, such as a seed, nut, pod, or cone, is buried in loose sand, and when the sand around it hardens and the object buried decays, there is left in the sand a perfect mold of the outside of the object, showing exactly its size and shape, but of course without a trace of the cellular structure. This mold may or may not be filled later. If it is empty a "squeeze" may be made by pressing into it soft wax or modelling clay, which, on the removal of the inclosing sand, forms a cast showing the size and the outside markings of the object making the mold. Occasionally a thin film of coal or coaly matter is found surrounding a nut or seed, which is all that remains of the original shell.

At many places where these casts of nuts and seeds are abundant it is possible to procure specimens so like their living analogues that it is hard to believe at first that they are really fossils. Many Carboniferous seeds, some of them large, are preserved as casts.

Sandstone casts of hollow stems are often found. The cast shown in *Figure* 7 was long supposed to be a distinct and peculiar

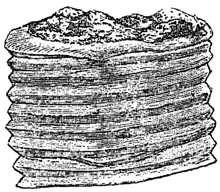


FIG. 7. Sandstone cast (*Artisia*) of pith cavity of a Carboniferous tree.

plant, but a specimen found in England proved that it is a cast of the pith cavity of a very common Paleozoic tree. The regular partitions of the pith, as seen in the figure, give the cast the appearance of a pile of coins.

HOW AND WHERE TO SEARCH FOR FOSSIL PLANTS

A question that is almost certain to be asked is, How and where should one search for fossil plants? In the first place, there is little use in looking into any but sedimentary rocks—that is, rocks that were deposited in water or by the action of water—for rocks that were poured out in a molten state would instantly have burned up any plants with which they came into contact,

though occasionally a charred tree trunk or similar object has been found. Nor is there much hope of success in looking for plants, other than seaweeds, in rocks that were deposited in salt water. Of course land plants are sometimes found in marine beds, though most of them are fragmentary and badly torn and worn by waves. Nearly all the fossil plants yet collected have been found in fresh-water deposits.

Fossil plants are likely to be found in the vicinity of a coal mine, generally not in the coal itself, though occasionally they are found in it, but in the rocks just below or just above the coal, or in the rock partings between the beds of coal. Some of these partings contain beautiful impressions of plants. Fine plants may also be found by splitting open blocks of the refuse rock material that is piled up in great "dumps" about the mouths of some mines.

At many pits where clay is being taken out to make bricks, tiles, or the like, layers of the clay contain well-preserved remains of plants. In fact, any clay bed is likely to repay a search. Such beds are exposed in many new cuts made for railroads or for street extensions or in grading. These places are especially inviting because large quantities of material can be worked over without much digging. The workmen who are taking out the material may be able to direct the student to favorable places.

In great open places where there are only natural exposures of rocks plant-bearing beds may perhaps be found by walking along the base of a slope or up and down along its sides, and where fragments of impressions are seen on loose pieces of rock that have fallen down these pieces may be followed up the slope until the bed from which they came is reached.

After a little experience the collector will learn for each locality the places and the kinds of rock that are most likely to yield remains of plants, and these he may search as thoroughly as his time and inclination permit. He should remember, too, that aside from gratifying his own interest he has always a chance of finding a specimen that is not only new but that may be of immense value to science. The humblest collector has just as good a chance as the trained specialist to find the unusual or the unique specimen.

HOW TO COLLECT FOSSIL PLANTS

The implements needed in collecting fossil plants are few and simple. The essential implement is a hammer, preferably like that shown in *Figure* 8, which has a square-faced steel head on one side and a thin cutting edge on the other. The thin face is especially useful in prying out and splitting the harder rocks. A pick and bar will be found useful in loosening large pieces of rock, and a stout cold chisel is handy in splitting and trimming hard shale.

The collector should provide himself with plenty of soft tissue paper for wrapping small, delicate specimens, as well as newspapers for wrapping large specimens that are preserved in hard rock. Each specimen should be wrapped separately; specimens that are carried loose and unwrapped will almost certainly be scratched and injured. A collecting bag, preferably of canvas or leather, should also be carried.

In making a collection it is desirable to procure as complete a representation as possible of the fossil flora found at each place studied, and to this end the specimens, as they are taken out of the

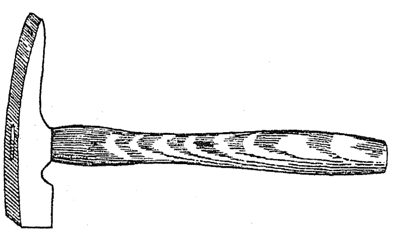


FIG. 8. Collecting hammer.

rocks, should be laid aside, out of the way of the collector's operations, until the time available or the material at the locality studied is exhausted. Then the specimens may be looked over and those obviously similar made into little piles, care being taken to get a full representation. Each pile, which presumably represents a single species or genus, may be again examined and the best or most perfect specimens in each pile selected for preservation. This method will insure a full representation of the flora. Specimens that are preserved in clay may be trimmed with a knife in the field, but the clay should not be allowed to dry out in the sun, as it may crack or disintegrate.

In the laboratory a small square-faced hammer and a series of chisels of different sizes should be provided, the hammer for trimming off superfluous material and the chisels for excavating partly exposed specimens. Many of the small instruments that are discarded by dentists as worn out will be useful in digging out small and delicate specimens.

As each specimen comes into the laboratory from the field it should be permanently numbered, either by attaching to it a separate label bearing a number, by scratching a number on it with a sharp-pointed instrument, or by writing or painting a number on it with a brush or pen. All specimens from a single lot should bear also the same lot number. The number of each specimen should be recorded in a record book, or catalogue, which should give all field data relating to it, including the exact location at which it was collected, its supposed age, the name of the collector, and the date of collection. This "Lot Catalogue" is absolutely essential, for if dependence is placed on loose labels or on memory the specimens are likely to get mixed or misplaced and their scientific value thus greatly impaired if not entirely destroyed.

COLLECTIONS OF FOSSIL PLANTS AVAILABLE FOR REFERENCE

The student or reader who has become reasonably familiar with the literary or "book" side of paleobotany—the science of fossil plants—will naturally wish to see some of the fossil plants about which he has been reading. In institutions in which formal instruction in paleobotany is given, there will of course be more or less extensive collections of fossil plants and other illustrative material, to which the student will have access, but for the benefit of the casual student, who may not know just where to find collections or exhibits of fossil plants, the following brief notes are offered.

The largest collection of fossil plants in this country, perhaps in the world, is in the United States National Museum, in Washington. This collection includes more than 500,000 specimens, which have been collected from practically all the known plant-bearing beds of North and South America, and is especially rich in type specimens—that is, specimens that are the basis of published names, descriptions, and figures of species new to science

or otherwise valuable or significant. A large exhibition hall is devoted to fossil plants, which are arranged in geological sequence from the oldest to the most recent and include many remarkably fine specimens. Wall cases contain collections of logs and pieces of fossil wood, many large trunks of cycads, and at the end of the hall there is a typical ledge of rock from Montana showing the fossils embedded in rock. The study collections, which fill hundreds of trays, are cared for in the paleontological laboratory, where they are accessible to all students and interested visitors.

The paleobotanical work of the United States Geological Survey is also performed in the National Museum, where there is maintained a library of about 8,000 volumes and pamphlets on fossil plants; a "compendium of paleobotany," which includes a bibliography of papers relating to fossil plants, now embracing about 20,000 titles; and a card index of every known generic and specific name that has been applied to a fossil plant. This index includes over 5,000 genera and nearly 40,000 species. All this material is available to students.

Many colleges and universities, especially those in which instruction is given in paleobotany or in which a museum is maintained, contain collections of fossil plants. Among these are the Johns Hopkins University; Columbia University, whose collections are displayed in the museum of the New York Botanical Garden; Yale University, whose collection is especially rich in cycad trunks; Harvard University, whose collection of fossil plants may be seen in the Museum of Comparative Zoology; the University of Chicago, which has large collections of Carboniferous plants from Illinois and Kentucky; the University of Colorado, which contains large collections from the celebrated Miocene beds at Florissant, Colorado; and the University of California, with collections rich in Tertiary plants of the Pacific Coast. Exhibits of fossil plants may be found in most museums, such as the New York State Museum at Albany, which is rich in Devonian plants, and the Carnegie Museum of Pittsburgh.

Chapter I

THE CRUST OF THE EARTH AND ITS DIVISIONS

IN any part of the world where we may happen to be, if we look out over the landscape—the hills, mountains, valleys, plains, and perhaps the distant sea—we can hardly fail to be impressed by the appearance of solidity and permanence. Those features not only look as if they had always been as we now see them, but they seem likely to remain unchanged. But let us look about us a little more closely and see whether these features are as unchanging as they seem.

In order to discover whether changes have occurred at any given place and to determine their extent and character we must have means of comparing the present conditions at that place with the conditions that prevailed there at some time in the past. The savage believes that the mountain which rises high before him has always stood just as it stands now or that it was made magically long ago in its present form by some being like himself, though mightier. But the geologist, in his quest of the truth concerning the features of the earth and their history, finds that certain beds of rock in the mountain, near its top, contain sea shells, or impressions of sea shells, which belong to forms of life that are found only in sea water. It therefore becomes obvious to him that those beds of rock once lay at the bottom of the sea, instead of rising thousands of feet above its level. Once upon a time, evidently, no mountain rose there.

We need not be geologists to discover that small changes are continually occurring at and near our mountain. If we visit it from time to time we shall see that the rainwater which falls on it is gathered into rills and rivulets, which, in flowing down its sides, cut channels and gorges and carry along earth, sand, and gravel and deposit them here and there in patches or beds—just such beds as make up a geological formation. So, for ages, rain water and other natural agents, such as heat, cold, ice, and wind, have been doing exactly what they are doing today—that is, wearing down the rocks. No matter how soft or how hard the rocks

may be, they are slowly but surely worn away. The mass of the land, including even the hardest of rocks, is thus being continually worn down and reduced to fine material, which is being carried away, mainly by streams, and laid down elsewhere as sediment. This loosened and liberated rock material, this sediment, which consists of gravel, sand, and fine clay or mud, may be carried for varying distances, some of it even for hundreds of miles, but sooner or later it reaches quiet water and sinks to the bottom. It may find a resting place in a slow-flowing stream, a pond, a lake, the mouth of a river, or the ocean, or, by a sudden rush of water, as in a freshet or so-called cloud-burst, it may be spread over the land. The wind, too, sweeps up dust and sand from one place and deposits it at others. Every century about nine inches of rock and soil is being worn away from the land of the North American continent and deposited elsewhere, usually under water. Rocks and beds of water-deposited material are called *sedimentary rocks*, and these are practically the only rocks that contain remains of plants and animals.

Sediment may thus be laid down at one place indefinitely, or as long as all the conditions are practically unchanged, and in this way thick beds may be deposited, as they were, for instance, in Shasta County, California, where an unbroken thickness of more than 30,000 feet of beds was laid down. Then something may happen to change the conditions. Perhaps the hills or mountains that were supplying the sediment are worn down so much that the streams can cut out no more material from them; perhaps a stream may break through a barrier and bring in sediment from another place; perhaps the basin or depression in which the sediment is laid down may become completely filled up, so that the flow of sediment is turned into another basin; or perhaps beds of sediment that are laid down flat under the water may be pushed up out of the water by movements or changes in the earth's crust, and may be crushed, broken, folded, or even gradually thrust up into mountains.

This wearing down of the rocks—*erosion*, as it is called—has been going on ever since the first rocks of the earth's crust appeared above the waters. Great mountains have been worn down and the materials composing them spread far and wide, and others have taken their places, only to be worn down in their

turn; and thus we see that our familiar hills and mountains, though they seem so everlasting, are really being worn away before our very eyes, though of course so slowly that we can hardly appreciate it.

Probably the first sedimentary rocks that were laid down, when the earth was young, were later worn away (*eroded*) and the resulting sediments were transported and redeposited elsewhere; and these operations may have been repeated many times before deposits were made that still remain where they can be seen and studied. Perhaps some of these older sedimentary rocks now lie beneath the sea, or are deeply covered by later rocks; in any event they may be where they cannot be reached by man.

Since the deposition of the sedimentary rocks first began, they have been built up to an estimated thickness of sixty miles. This estimate does not imply that they attained this thickness at any one place; but by adding together the thicknesses of rocks of different ages over all the world we get this enormous thickness. Beds have been built up and torn down from time to time, and this process of building up and tearing down and then building up again is still going on.

These sedimentary rocks, then, must receive our special consideration, for, as has already been stated, they are almost the only rocks that contain fossils. Geologists have divided these rocks into a number of major groups, and these again into smaller groups, each based on some characteristic feature, but more particularly on the kinds of fossil plants and animals found in them. It has thus been possible to work out a fairly complete story of the progress of the plant and animal life of the world from its beginning in the remote past down to the present; and although there are still many breaks or blank places in this story, it is gradually being made more and more complete as additional facts come to light.

This story has been worked out on what is called a *time scale*, which is generally expressed in columnar form, and much of the work of geologists is devoted to perfecting it. This time scale or geologic column may be roughly compared to a pile of huge volumes, an encyclopedia of earth history, so to speak, in which the fossils are the illustrations. We may carry this simile a little further. A printed history may consist of several volumes, some

of them grouped together to cover certain more or less closely related events, and the individual volumes are divided into sections, chapters, and paragraphs. The sedimentary rocks of the earth's crust are similarly divided into sixteen "volumes," only we must call them not "volumes" but *periods* or *systems*, *period* denoting time and *system* denoting rocks, and these sixteen groups have been brought into five larger groups, called *eras*. Each period or system may be divided into one or more *epochs* or *series*, and these in turn into *ages* or *stages*, these pairs of terms also denoting time or rocks, respectively. There are also still smaller divisions of the rocks, the smallest being what is called a *formation*. The following table shows these divisions, with the oldest at the bottom and the youngest at the top.

The reader who is unfamiliar with geology may at first think that these terms are somewhat formidable, but as many of them will appear again and again in the following pages, he will have to learn them in order to understand the sequence of geologic events. All attempts that have been made to express them in simpler words or phrases have resulted only in confusion and failure. They belong to the language of geology. They are not arbitrary or meaningless words given to impress or to confuse the reader; they are terms that have very definite meanings, which are usually connected in some way with the rocks or with the places where they were first studied or the conditions under which they were deposited. Thus the Cambrian period is from Cambria, the ancient name for Wales, where the rocks of this period were first recognized; Jurassic is from the Jura Mountains, a short range of mountains between France and Switzerland, where rocks of this period were early studied; Cretaceous is from the Latin word meaning chalk-like, for the beds in the vicinity of Paris to which it was first applied are composed largely of chalk; Tertiary is from the Latin tertiarius, meaning containing the third part, in allusion to the third of the three parts into which the rocks of the earth were originally divided.

Geologists have estimated carefully the relative length of time represented by each of the principal units into which the sedimentary rocks are divided. If the whole time represented by the geologic column is 100, it appears that at the end of the Archeozoic era 30 per cent of geologic time had passed; yet in the

PRINCIPAL DIVISIONS OF THE SEDIMENTARY ROCKS OF THE EARTH'S CRUST, ARRANGED IN ASCENDING (NATURAL) ORDER

Era	Period	Epoch	Maximum Thickness
Cenozoic era (modern life). Age of flowering plants.	Quaternary........	Recent Pleistocene	5,000 feet of clay, sand, and gravel
	Tertiary.............	Pliocene Miocene Eocene	32,000 feet of clay, sand, gravel, sandstone, limestone, and coal
Mesozoic era (middle life). Age of cycads, conifers, and primitive flowering plants.	Cretaceous......... Jurassic Triassic	Upper Lower	65,000 feet of sandstone, shale, limestone, and coal
Paleozoic era (ancient life). Age of ferns, lycopods, calamites, and seed ferns.	Carboniferous.... Devonian Silurian Ordovician Cambrian	Permian Pennsylvanian Mississippian	70,000 feet of shale, sandstone, limestone, and coal
Proterozoic era (primitive life). Age of primitive plants—algae, bacteria.	Keweenawan		30,000 feet of conglomerate and sandstone, with lava
	Animikian		14,000 feet of banded slate, and schist, with iron ore
	Huronian		10,000 feet of glacial conglomerate, quartzite, and limestone
	Sudburian		20,000 feet of quartzite
Archeozoic era (primal life?). Age of probable unicellular life.	Keewatin Grenville		100,000 feet of sedimentary schist, gneiss, lava, slate, and limestone

NOTE.—The pre-Cambrian periods are by some grouped together under the name Algonkian.

sediments laid down during that time not a single recognizable trace of life of any kind has been found. The Proterozoic era adds 25 per cent, so that the first two eras make up more than half of geologic time, yet during this 55 per cent only algae and

bacteria appear to have existed—at least we have found in the rocks of those two eras the remains of only those forms of life. A further addition of 17 per cent brings us to Devonian time, in which, so far as the record shows, the first land flora appeared. The Archeozoic, Proterozoic, and Paleozoic eras together mark the passage of 85 per cent of geologic time. The Mesozoic era, although it witnessed wonderful changes and advances in plant life, covered only 11 per cent of the time, and the Cenozoic era only 4 per cent. The Pleistocene epoch, the so-called Great Ice Age, which may have lasted half a million years, represents 0.12 per cent of geologic time, and the time since the ice disappeared is estimated at only 0.005 per cent.

A question that is almost certain to be raised is, "How old is the earth? What is the probable length of geologic time in years?" The data required to supply an answer to this question are very complicated and cannot be fully given here. In the effort to supply an answer, astronomers, mathematicians, physicists, and chemists, as well as geologists, have been consulted, for the problem lies in part within the field of each of these classes of students. Many years ago a distinguished geologist thought the earth might be no more than 20,000,000 years old. A little later a distinguished astronomer expressed the opinion that it might be 50,000,000 years old, and an equally distinguished physicist was willing to allow 100,000,000 years. Another geologist estimated its age at 400,000,000 years, but this estimate was generally considered too high, and for many years it was thought that perhaps 200,000,000 years was a reasonable estimate. Suddenly, a few years ago, radioactivity, then just discovered, seemed to give a more reliable estimate than anything before known, an estimate indicating that it can hardly be less than 750,000,000 years old and may indeed be twice that old, or 1,500,000,000 years! These figures simply stagger the imagination, and although they are only estimates, perhaps the best that can be made with the facts at hand, they at least show that geologic time has been vastly long.

Chapter II

CLASSIFICATION OF LIVING PLANTS

BEFORE we begin to study the plants of the past we may with advantage consider the living plants and note the groups into which they have been divided or united and the manner in which these groups are related to one another—in other words, we may profitably consider the classification of plants.

Let us take, for example, the pines, the oaks, and the roses. A pine tree is known by its deeply furrowed bark; its slender needle-shaped evergreen leaves, which are borne in clusters containing one to five leaves; and its fruit—a woody cone made up of closely lapping scales, each bearing two winged seeds on its upper surface near the base. If now we should travel over the world seeking all trees that agree essentially with this description, we should in the end have brought together about eighty different kinds (species), and we should have learned a good deal about their size, the number and the length of their leaves, and the size and shape of their cones. These eighty species make up the group (genus) of pines.

At the time we were hunting for the different kinds of pines, if we had also brought together all trees and shrubs that agree with the pines in having seeds borne on scales that are grouped together in a cone or a modification of a cone we should have some thirty groups comparable to the pine group, and these groups would make up the larger group known as the true cone-bearers (conifers, or *Coniferales*). The conifers include some of our most valuable timber trees, and they or their relatives have played a prominent part in the history of the plants of the past.

The oaks are well known to everyone, and if we bring them all together we shall find that there are nearly three hundred kinds. These may differ widely in the size of the trunk and in the size and shape of the leaf, but they agree in having the fruit in the form of a nut or acorn, which has a circular scar at its base, where it sits in a saucer-shaped cup. These make up the group (genus) of oaks (*Quercus*).

There are several groups that differ somewhat in various ways

from the oaks but that agree with them in having the fruit in the form of a nut that is more or less enclosed in a woody or spiny covering, known to botanists as an involucre. In addition to the oaks these groups include the beeches, the chestnuts, the golden-leaved chestnut, the so-called tanbark oaks, and a peculiar beech tree living only in the extreme southern end of South America. These six groups (or genera—plural of genus) make up the larger group known as the beech family (*Fagaceae*).

The roses that are most familiar to us are of course those of greenhouse and gardens, which bear large double, brightly colored flowers, but these are not found in a wild state; they have been produced from wild roses by cultivation. The species of wild roses number more than a hundred and agree among themselves in having erect or climbing, usually prickly, woody stems and flowers having five large, brightly colored petals and seeds enclosed in a berry-like fruit called a rose-hip. They also agree in having compound leaves—that is, their leaves are composed of several small leaves, called leaflets, arranged on both sides of a common stem—and in having flowers in which the parts are arranged in a way that is peculiar to the roses.

Botanists—students of living plants—have found no less than ninety other groups that agree with roses in certain important particulars, and these groups make up the great rose family (*Rosaceae*), which includes more than two thousand kinds (species) of plants. And these numerous plants, as we might naturally expect, differ greatly in size and in general appearance; some are tiny herbs, scarcely an inch high; others are lofty trees; yet the signs of rose kinship runs through them all. Some, like the roses, have been cultivated and improved for their beautiful flowers; others, such as the strawberry, raspberry, apple, peach, pear, plum, and cherry, are grown for their edible fruits.

Working in the manner indicated for the pines, oaks, and roses, botanists have brought together in groups of different sizes all the known living plants of the world, which are of some 200,000 different kinds or species; and this bringing together in orderly arrangement is what is called plant classification. But not content with bringing plants together into families, such as the beech family or the rose family, they have brought them together into larger and still larger groups, until finally they have formed a

great group that includes all plants, as compared with the great group that includes all animals. And still further, they have so arranged the groups as to show, as nearly as our present knowledge will permit, the degrees of relationship or kinship between them, beginning with the simplest and passing gradually to the more and more complex. This work is one of the most difficult parts of plant classification, because many of these relationships are not easy to find, and because new facts are being continually brought to light that may modify or even completely change earlier views. One great value of the study of fossil plants is the light that it may furnish in solving this complex problem of relationship.

A brief outline of the nomenclature of plant classification, showing the several grades and their values, may be of interest, and it should be kept well in mind, for many of these names will be used again and again in our study of fossil plants.

The simplest grade or unit is a group of individuals that are obviously alike and that are able to reproduce their kind. Such a group is called a *species*. All the species that have certain features in common, though they may differ among themselves in minor particulars, together make up a *genus*. Thus all the oaks belong to the genus *Quercus*, all the roses to the genus *Rosa*. In like manner, when all the obviously related *genera* are brought together the group is called a *family*. Related families are grouped together to make an *order*, and related orders are grouped together to make a *class*, and classes are in turn combined to make a *phylum* (plural, phyla); and the final group includes all plants and constitutes the vegetable *kingdom*.

Every known plant, both living and fossil, is designated by two Latin or Latinized names, showing its genus and species, and no two or more plants may rightly have the same name. Thus *Quercus alba* is the scientific name of the white oak, *Quercus rubra* of the red oak, *Rosa setigera*, the prairie rose. The question is often asked: "Why is it necessary to give a common and well known plant a long Latin name? Why not call it a white oak, or a red oak or a prairie rose?" The answer is really very simple and convincing. If only one language were spoken in all the world—English, for example—and if each plant had but one common name, this name might perhaps meet all reasonable needs; but

there are many languages, and every country might claim, with equal show of right, that each plant, even if it happens to grow in many countries, should be known only by the name used in the language of that particular country. Such a practice would obviously lead to hopeless confusion, for even in English alone many a plant of wide distribution has from two to a dozen common names. For example, in the northeastern part of the United States, no less than twenty-one distinct species of plants, belonging to ten genera and eight families, are known as "snake root." Then we must remember that relatively few plants have common names and being thus nameless they could not be mentioned intelligently at all if we had no universal, all-inclusive system of scientific nomenclature.

Latin is the universal language of science, and no matter what or how many common or popular names a plant may have in any language, it has but one Latin name the world over—a name that is recognized and understood by botanists and students everywhere. The scientific names of many living plants seem formidable because they are not commonly employed; no one is much distressed by the Latin names that are in everyday use, such as geranium, magnolia, chrysanthemum, nasturtium, begonia, petunia, narcissus, dahlia.

The following table shows in outline the principal groups into which the vegetable kingdom may be divided, beginning with the lowest or simplest plants and ending with those that are regarded as the highest. Many systems of plant classification have been proposed, but the system here given, although it does not adequately express our present knowledge of inter-relationships and affinities, has at least the merit of long and familiar use.[1]

PRINCIPAL DIVISIONS OF THE VEGETABLE KINGDOM

Thallophyta: Algae (sea weeds), fungi, bacteria, diatoms, slime molds.

Bryophyta (mosses and allies): Liverworts and mosses.

Pteridophyta (ferns and fern allies): Ferns, horsetails, club mosses, etc.

Spermatophyta (seed plants): Conifers, cycads, joint-firs. Flowering plants (monocotyledons and dicotyledons).

[1] Those who may wish to pursue this subject further should consult an article by D. H. Campbell in *Science*, Vol. LXI, April 17, 1925, p. 403.

A complete classification in outline of the familiar red oak, *Quercus rubra*, for example, will stand as follows:

Species	*rubra*
Genus	*Quercus*
Family	*Fagaceae*
Order	*Fagales*
Subclass	*Dicotyledonae*
Class	*Angiospermae*
Phylum	*Spermatophyta*
Kingdom	*Vegetabilia*

It may be added in passing that the classification of animals is essentially the same as that outlined above for plants, the only difference being that the names assigned to certain of the units have slightly different values. The results attained, however, are practically identical, differing only in minor particulars.

Some fossil plants obviously belong to established groups of living plants; others belong to groups that are wholly extinct, so that genera, families, orders, etc., must be provided for them. Each of these extinct groups is then placed as close to the nearest of its living kin as the known facts concerning its affinities will permit.

It may be of interest to compare the number of species of plants in the living flora with the number in the fossil flora. It is difficult, however, to give satisfactory statistics showing these numbers, for new forms are being continually described, and there are differences of opinion as to generic and specific limits. The following figures are perhaps the best that can now be given.

SPECIES OF LIVING PLANTS

Angiosperms (flowering plants)	125,000
Gymnosperms (conifers, cycads)	600
Pteridophytes (ferns, lycopods, horsetails)	10,000
Mosses and liverworts	9,000
Fungi and bacteria	50,000[2]
Lichens	6,000
Algae (sea weeds)	15,000
	215,600

[2] A recent estimate (*Science*, April 17, 1926) places the number of species of fungi at approximately 100,000.

These figures represent only plants that have been described and named. When the total living flora has been made known the number of species may well exceed 300,000.

Accurate statistics regarding the known fossil flora of the world are difficult to ascertain, for the descriptions are widely scattered in literature, many identifications are obvious duplications, and not a few plants are so imperfectly known that they can not yet be placed with certainty. We know, however, that there are more than 5,000 genera and more than 40,000 nominal species. The custom of giving generic and specific names to more or less obscure fragments has often been questioned, especially by botanists, but it is adequately defended on the ground that it affords a convenient means of designation and avoids tiresome repetition or circumlocution. Care should be taken to avoid giving names that imply a degree of kinship that is hardly warranted by the facts.

The following figures cover the Mesozoic and Cenozoic floras of North America, which may be taken as a fair representation of the floras of those eras in other parts of the world:

SPECIES OF MESOZOIC AND CENOZOIC PLANTS OF NORTH AMERICA

Angiosperms	3,481
Conifers	576
Ferns and allies	450
Mosses and liverworts	17
Lichens	2
Fungi	23
Algae	41
	4,600

These 4,600 species belong to 843 genera.

Dr. G. R. Wieland has recently published an interesting speculation as to the possible number of species of plants that may have existed during past geologic time. He says:

"With due regard to the fossil record there may have been in existence at the base of the Cretaceous about a round hundred thousand species of plants; in the Jurassic forests, 60,000; in the Permo-Triassic, 43,000; in the Carboniferous, 27,000; and in Devonian time a possible 12,000 species."

Chapter III

THE FIRST FORMS OF LIFE

SOMEWHERE, somehow, sometime, life began or in some way manifested itself on the earth. There has been a great deal of speculation as to the conditions under which life originated—that is, whether it originated at only one time and place or at many times and places—but we are still without a wholly convincing answer to the question.

The views advanced by some students that life has been brought in from a source outside the earth and that one or more of the planets of our solar system support some form of life are absolutely without proof or disproof. It is true that two planets—Venus and Mars—apparently possess atmospheres and exhibit climatic conditions that may permit the existence of some form of life as we know it, and that there are certain activities and seasonal changes on Mars that have been interpreted as indications of the presence of life, but convincing proof as to their significance is still lacking. Even if we suppose that life was brought to the earth from an outside source the supposition would simply set the problem of its origin a step further back. But whenever or wherever or however life began on the earth, we must make its existence our starting point.

As our knowledge of the beginning of life is so vague and imperfect, it naturally follows that we are very much in the dark as to the nature of the first form of life. What was it like? Was it plant or animal in form and function, or was it a simple cell that could be called neither plant nor animal, but from which both plants and animals could have been developed? The fact that the food of all animals is directly or indirectly supplied by plants seems to justify the assumption that plants were actually the first forms of life to come into existence, or at least the first to take definite shape. It might well be that even if we could see and study the first forms of life we might find it difficult if not indeed impossible to decide whether they were plants or animals, for there are such organisms living today. Of course we have no

difficulty in distinguishing between the plants and the animals that we see about us on every hand, but as we go downward in the life scale, we find that the plants and animals become simpler and simpler in form and structure, until we come to a sort of border line—a no-man's-land, so to speak—where it is very difficult to decide whether a particular organism shall be called a plant or an animal. An example may be seen in the so-called slime-molds (*Myxomycetes*), the yellowish or orange-colored slimy masses often seen on rotting logs. Although now usually regarded as plants, they have by some been placed in the animal kingdom. Likewise there are certain minute simple organisms known as protozoa, that are now almost universally regarded as animals, and yet some of them have not infrequently been placed in the plant kingdom. In fact the line between the two kingdoms is so hard to draw that it is found impossible to word a definition that will include all possible plants, and as uniformly exclude all possible animals. About the best we can do is to define a plant as an organism that in general subsists on inorganic substances and, conversely, an animal as an organism that in general subsists on organic substances.

Of course difficulties of application immediately arise, for there are certain plants, such as many bacteria, that draw their food supply from both plant and animal substances, and also certain protozoa that not only possess chlorophyl (the green coloring matter of the higher plants), but can also manufacture their food from simple inorganic elements. But these saprophytic bacteria are thought to have degenerated, or at least descended, from ancestors that originally obtained their food from inorganic materials, and the protozoa mentioned above may, at certain stages in their life history, assume a different form, and then take in solid food, and, so to speak, eat like animals. The difference between these plants and animals that stand on the border line between the two kingdoms, is, therefore, more or less an academic question and is best left to the biologists.

The first forms of life were undoubtedly very simple, probably hardly more than very minute bits of a jelly-like substance (protoplasm), not unlike white of egg in appearance, with little or no trace of a wall or other enclosing membrane, but possessing the marvellous power of *taking in food*, *increasing in size* (*grow-*

ing), *excluding waste, and reproducing their kind*. These are the supreme marks of all living things, and serve to distinguish them at once from all inorganic things. These early forms of life must have propagated their kind by the very simple process of dividing into two similar parts, and each of those again into two, and so on, each part having the character and appearance of the parent mass. It is reasonably certain that this must have been the process, because there are many simple plants and animals living today that increase in this way.

This jelly-like substance, protoplasm, is in many respects the most wonderful substance known in the world, for all the forms of plant and animal life, from the lowest and simplest to the highest and most complex, are made of it. Protoplasm has been analysed or taken apart by chemists, and is found to be composed mainly of compounds or mixtures of carbon, hydrogen, oxygen, sulphur, phosphorus, and often minute quantities of many other substances. These analyses show, of course, the composition of dead protoplasm. Living protoplasm is a very complex, highly organized substance, with structures that can hardly be made out even with the most powerful microscope. They are far too complicated to be entered into at this time, and we must go on with what are assumed to be the steps after the first forms of life were established. Probably one of the first onward steps in its progress was the formation of a wall that surrounded and protected that otherwise naked bit of protoplasm. It had then become in effect a little box, or cell, as it is called, and the cell is the unit out of which all plant and animal structures are built, just as a brick is the unit of which a house may be built. Probably for millions of years, plants did not progress beyond the single, simple, one-celled stage, but sooner or later the cells combined and assumed different forms as they were put to different uses. Some cells, or sets of cells, were especially adapted to strengthen and support the organism; some were engaged in taking up the food materials and carrying them to cells where this crude material was made into plant food, or where it was stored up for future needs; and still other cells were devoted only to the processes of reproduction. Of course these complicated and complex structures and uses were not evolved until plant life was well on its way to

the plants of the present day; but the point to be borne in mind is that they are all based on the cell and its contents.

These simplest forms of early plant life must have been produced, or at least have lived, in an environment that supplied abundant moisture, probably directly in the sea. They must have been so minute and unprotected, that, if they had been exposed to light and dry air, they would have dried out and been killed in a very short time. These supposed earliest forms of life have left no direct traces in the rocks, which is hardly surprising when it is remembered that they were very minute and had no hard parts that could have been preserved, and further, that during the hundreds of millions of years that have since passed, the ancient rocks in which they should be found have been folded, and faulted, and crushed, until little of their original form remains. However, even if it is not possible to recognize definite and distinct remains of plants in these ancient rocks, it is possible to infer their presence with a more than reasonable degree of certainty by things or conditions that apparently could have been brought about only by or through the action of plants. In this process, bacteria are thought to have taken a very important part.

Bacteria are minute one-celled plants. They are the simplest and smallest of known organisms.[1] Although many hundreds of different kinds are now known, there are only three principal shapes, namely, spheres, rods, or spirals, which have well been compared respectively to billiard balls, lead pencils, and corkscrews. They are, of course, all invisible to the naked eye, and are so almost incredibly small that if a thousand of the rod-like forms were placed end to end they would hardly make a line long enough to space the diameter of the dot above a letter "i" on this page. They multiply by division, and so rapidly that in one

[1] An exception to this current belief is apparently necessary to cover the case of the so-called filterable viruses. It has recently been demonstrated that certain obscure diseases of man and animals can be communicated by inoculation with a virus that passes readily through an ordinary filter such as is used in chemical laboratories, and the consensus of opinion favors the theory that these diseases are caused either by minute organisms that cannot be demonstrated by our present methods, or by organisms that are so exceedingly minute that they are beyond the power of the microscope to detect. There are also certain diseases of plants, such as the so-called mosaic diseases, that are believed by many to be caused by similar ultramicroscopic organisms, but complete agreement has not yet been reached by students.

day a single one may have multiplied into more than 16,500,000, and in two days to about 281,500,000,000.

Bacteria are found at the present time practically everywhere in the world, or at least where any other plant or animal can live. They are found in the soil, in the water (both fresh and salt), and in the air, where they have been carried on dust particles, and some can withstand temperatures from that of boiling water (for a short time) to that of solid ice. Although many forms of bacteria are killed quickly when exposed to air and sunlight, there are others that may retain their vitality for an unknown number of years, as shown by an interesting experiment made at the University of California. Samples of soil taken from many places, including the desert, were kept in the laboratory there at ordinary air temperatures for thirty years, and when the soil was moistened it was found that great numbers, especially the desert forms, were alive and ready to go on with their work.

A very great variety of food substances are made use of by bacteria. Some get their entire nourishment from inorganic substances; some require the presence of oxygen, while others can live only in the absence of free oxygen. They are the active causes of decay, fermentation, and many diseases of both plants and animals. This disease-producing habit has given bacteria a very bad name to the general public, for some of the most dreaded diseases of man are chargeable to them, yet as a matter of fact out of the hundreds of kinds known there are only a few—perhaps a dozen or twenty—that fall within this list. The other kinds are either harmless so far as the higher plants and animals are concerned, or they are actively engaged in making conditions possible for other higher forms of life. Some are removing dead matter of all kinds; others are preparing the soil, or taking nitrogen from the air and making it available for plant food; in fact, in a thousand ways, they are preparing earth, water, and air for the use of other forms of life. Indeed, so important are the bacteria, that all life would stop if they should suddenly be blotted out of existence.

A most astonishing discovery of living bacteria at great depths in the earth has recently been announced by Professor E. S. Bastin, of the University of Chicago. He made chemical and bacteriological analyses of oils and associated waters taken from

continuously flowing oil wells in the southern Illinois oil field, at depths between 500 and 1500 feet below the surface. Samples from twenty-five oil wells were examined in the bacteriological laboratory, and in twenty-three an abundance of living bacteria were found. They are essentially similar to bacteria found on or near the surface.

The problem of a food supply a thousand feet or more below the surface naturally presents itself. On this point, Professor Bastin says: "The lack of sulphates and the presence of hydrogen sulfide gas leads us to believe that the minute organisms are eating the sulphates and giving off sulfide gas as a waste product in their simple bodily processes."

This brings up an interesting speculation as to how they reached their present position, often below seemingly impervious layers of rock, and, further, the length of time they may have been there. Were they carried down by percolating surface waters, or were their ancestors buried millions of years ago, when the rocks were deposited? These questions may never be answered. If there has been no contamination from outside sources in the study of these samples, then the presence of living organisms at such depths, certainly opens up a wholly new field of bacteriological activity.

The part bacteria are playing in the formation of limestone illustrates the part they have apparently played ever since the earliest sedimentary rocks were deposited. There are, for example, great beds of limestone many feet in thickness and covering hundreds of square miles in the oldest of these rocks of which there is knowledge, and long before we find any recognizable traces of plants and animals. Now, it has very recently been found that there are bacteria living in sea water that have the power of taking limestone (calcium carbonate) out of the water and depositing it in the form of an ooze on the bottom of the ocean. These bacteria grow best in shallow warm waters such as are found off the coast of Southern Florida and around the Bahama Islands. They are so minute that there are about 160,000,000 in a cubic centimeter of sea water, or in less than half a teaspoonful, and yet apparently they are slowly but surely building up beds of limestone similar to those mentioned above that are found among the oldest rocks.

Since the above observations were recorded, studies in tropical

Pacific waters, on identical as well as other organisms found in sea water, have failed to confirm the results announced above. It is thought that the calcium carbonate may have been derived from a lime-containing reagent employed in the investigation, rather than from the pure sea water. Further critical studies of normal sea waters in many parts of the world will be needed to settle the matter.

Doctor Walcott, the Secretary of the Smithsonian Institution, wrote as follows of the limestone-forming ability of algae and bacteria:

"The presence of minute forms of algae and bacteria in the ancient pre-Cambrian rocks was suspected for several years before they were found. From the part they both play in the deposition of calcium carbonate (limestone) in modern waters and the fact that bacteria are usually present when animal and vegetable matter is broken down by decomposition, it seems that they must have existed almost from the beginning of life on earth, and in this way we may explain the presence of limestone of pre-Cambrian (Algonkian) time that is found in Montana and other parts of North America."

The presence of undoubted bacteria has been proved in tissues of plants of Carboniferous time, and so perfectly preserved that they have been photographed and named. They have also been found in plant tissues, as well as in coprolites of reptiles and fishes, from Devonian to Jurassic time. In *Figure* 9 is shown a photograph, 1100 times natural size, of the bacteria found by Doctor Walcott in the above mentioned Algonkian limestone of Montana. This is probably one of the oldest forms of life that has thus far been found on the earth, and so many millions of years old that a statement of its age staggers the imagination.

But the formation of limestone is not the only evidence of the work of bacteria in these far distant times. There are certain beds of iron ore that are thought to have been formed by the agency of these minute plants. The manner in which this was accomplished is somewhat complicated, but probably came about where the bacteria, in decomposing organic matter contained in the water, liberated a certain amount of oxygen, and this in turn acted on the iron that was held in solution in the water, and changed it to a form of iron that was not soluble, which was

slowly deposited on the bottom of the lake, swamp, or other body of water, and this process going on for a long time gradually accumulated the beds of ore.

In many parts of the world, but especially in the Laurentian region of Canada, there are beds, or layers, of a black substance known as graphite, "plumbago," or so-called "black lead," which is so familiar to us as the "lead" in the ordinary pencil. It is not lead, but is a nearly pure form of carbon. The rocks in which this graphite is found in Canada are very ancient,—older even than

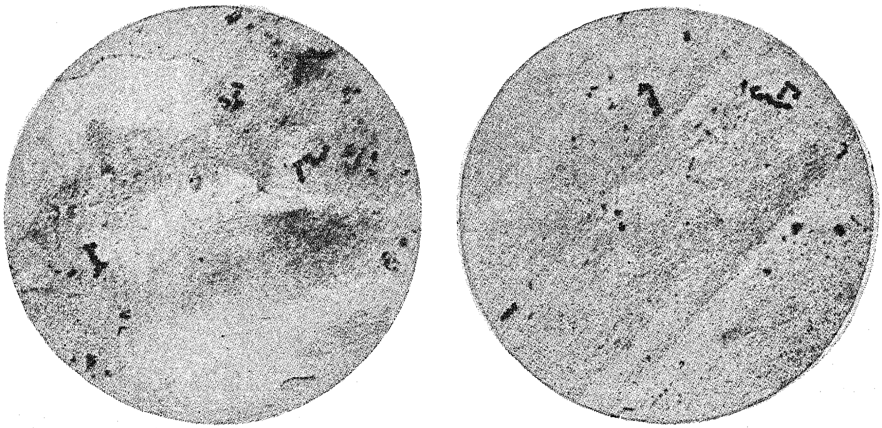


FIG. 9. Bacteria (*Micrococcus* sp.) from Algonkian limestone of Montana. Enlarged about 1100 diameters. After Walcott.

the Algonkian rocks of Montana already mentioned. Although no certainly recognizable remains of plants have ever been found in, or associated with, these graphite beds, it is believed that they were probably formed by the decomposition of organic matter by bacteria. It is well known that in the later geologic ages the beds of coal have been formed from the partial decomposition of vegetation of many kinds, as will be explained later, and, although it is also known that graphite can be, and sometimes undoubtedly is, formed by chemical processes, it is not thought that it could have been produced in this manner in quantities so large as we find indicated in the graphite beds of Canada. There is one difficulty, however, and it is a very real one, which is to account for the organisms that would be required to produce this amount of graphite. The only plants that are presumed to have existed at

that time had so little carbon in their substance that it would seemingly require an impossible quantity to be concentrated into these immense beds, which are sometimes as much as ten or twenty feet in thickness and consist of practically pure graphite. Be this as it may, the formation of graphite from plants is the most reasonable explanation that has been proposed, and it may be accepted until it is clearly shown to be wrong.

Sir William Dawson, writing on this subject many years ago, said: "It is deserving of notice that, if the Laurentian graphite indicates vegetable life, it indicates this in vast profusion. That incalculable quantities of vegetable matter have been oxidized and have disappeared we may believe on the evidence of the vast beds of iron-ore; and, in regard to that preserved as graphite, it is certain that every inch of that mineral must indicate many feet of crude vegetable matter."

The part played by bacteria in the formation of coal is another indication of their great antiquity. At the present time, beds of peat are being formed in swamps and bogs largely by the bacterial decomposition and breaking down of plant material, and as the process goes on it finally produces a mass of carbonaceous matter from which nearly all traces of the peat-forming plants have disappeared, and this matter ultimately becomes the coal as we know it. This will be more fully explained in the chapter on the formation of coal. The only point to be emphasized is that bacteria of the same size and appearance have been in existence and acting in the same way that they do today, as long as coal has been in the making,—that is as early at least as Devonian time, when the first land plants made their appearance.

What may have been the composition and temperature of the water of the early ocean, the probable habitat of the first forms of life, we can only speculate, but both undoubtedly exercised a more or less marked influence on those forms, and on this point there are a number of observed facts from which certain conclusions can be drawn. Our conclusions on this question will be influenced by the hypothesis we may accept as to the origin of the earth itself. If we accept the nebular hypothesis, which supposes the earth to have been condensed from an original incandescent nebulous mass thrown off from the sun, it follows that the moisture in the mass remained in the atmosphere until the crust of the

earth had been sufficiently cooled to permit it to be condensed to form the early oceans. According to this hypothesis it is practically certain that the early waters were not strictly pure; they must have contained certain dissolved gases, and acids, though it is reasonable to suppose that they contained lesser amounts of salts and other chemical substances than the present oceanic waters; in other words they were fresher, though just to what extent it is difficult to determine.

The alternative hypothesis, called the planetesimal theory, supposes that the earth was formed by the coming together from the surrounding space of small cold particles or bodies, which held the moisture locked (occluded) within them. As these bodies (planetesimals) became more and more concentrated at the center of the earth, their mutual pressure developed heat, and the heat expelled the moisture, squeezing it out, so to speak, and pushing it toward the surface, where it combined to form the original oceans (hydrosphere). If this view is accepted, it seems difficult, if not indeed impossible, to determine what substances (gases, acids, salts) were dissolved and included in the water as it was pushed toward the surface.

Although each of these hypotheses of earth origin is confronted by difficulties in the way of complete acceptance, there seems to be a growing consensus of opinion that the planetesimal hypothesis is less plausible, that is to say, it is confronted by more difficulties in the way of its acceptance, than the nebular hypothesis.

It is well known that the waters, as they percolate through or pass over the land masses, dissolve many substances from the rocks, which are ultimately carried into the sea or into lakes in which they are left behind when the water evaporates. Evidently there must have been a progressive concentration or accumulation of these substances in the sea with the passage of geologic time. Certain it is that the waters of the present oceans have a very complicated chemical composition, with traces or varying amounts of a great number of substances, the most conspicuous of which is of course the sodium chloride or common salt. On the whole, therefore, it seems a safe assumption that the waters of the early oceans were "fresher" than those of the existing oceans. Just what effect this condition may have had on the development of the first forms of life is difficult to determine.

The probable temperature of the early oceans is also a matter of interest and importance, in its possible bearing on the origin of life, but the necessary data on which to base a conclusion are not always easy to find or to interpret. In the later geologic ages, when the remains of plants and animals had become fairly abundant, very reliable conclusions can be drawn by noting the climatic requirements of their living kin, which are presumed to be the same as, or closely similar to, the conditions demanded by their ancestors. But in the ages before life appeared, or at least before it left definitely recognizable traces, other means of determination must be invoked, such as certain chemical actions and reactions that are known to have taken place. However, all things considered, it seems a wholly reasonable assumption that the waters of the early oceans were warm. For example, the earliest known plants that took part in the deposition of the beds of iron ore in Michigan are thought by Doctor Gruner, who has described them, to have required a sub-tropical or more likely a tropical temperature.

Whatever may have been the temperature at the surface of the earth when life was first evolved, it is certain that it has since been stabilized between relatively narrow limits, else life could not have been continuous, as there is every reason to believe it has been. The vital processes in plants are practically suspended when the temperature falls below 32° F., the freezing point of water, though during their resting stage many plants, especially in polar lands, can endure a temperature of —70° F., or even lower. The opposite extreme is shown by certain simple types of algae that thrive in the waters of hot springs under a temperature of approximately 200° F.—that is, only about 12° below the boiling point of water—and a considerable algal flora lives in hot springs whose temperatures range from 140° to 180° F. It is now known that certain bacteria and protozoa, when in a resting stage, can successfully endure a temperature of about —325° F. for six months, and about —420° F. for shorter periods. These extremes of heat or cold, however, are far greater than these organisms can endure when they are in active growth. It seems, therefore, that the limit of life toleration must be less than 200° F.,—that is to say, a permanent raising of temperature above 200° F. or a lowering below 32° F., would have inhibited plant life on this globe.

Chapter IV

THE DAWN OF PLANT LIFE

IN the last chapter some of the evidence was presented regarding the supposed origin and presumed existence of plants, not so much in the form of actual plant remains that can be seen and photographed, but plants that are inferred to have existed by the work they accomplished, such as that of building up beds of limestone, iron ore, and graphite. We have now come to the point where we can begin to consider what may be called real plant remains—remains that can be seen and studied and pictured.

So far as at present known, thanks to the studies of Dr. John W. Gruner, of the University of Minnesota, the earliest reasonably definite remains of plants are those recently found in connection with the well-known deposits of iron ore in northern Michigan, although, as already stated, their presence had been inferred before they were actually discovered. It now seems reasonably certain that minute organisms were present and widespread in lower Proterozoic (Huronian) time, including algae, bacteria, and probably bacilli. The reason they were not earlier observed is due to the fact that they are so exceedingly minute, requiring the highest powers of the microscope for their detection, that they were easily overlooked. When magnified a hundred times they are still almost invisible, and a magnification of five hundred to a thousand times is required before much can be learned about them. There were evidently several kinds.

The algal forms were slender, more or less worm-like, often branching organisms, that resemble very closely certain living blue-green algae, and they seem also to have been surrounded by a mucillaginous sheath, as are some living forms. Their appearance when greatly enlarged is shown in *Figures* 10 and 11.

Associated with the algal forms were bacteria, known as iron bacteria (*Figure* 12), that evidently took part in extracting the iron from the water and depositing it in an insoluble form. One difficulty is in finding waters sufficiently rich in iron to account for the widespread deposits, for ordinary surface water contains less

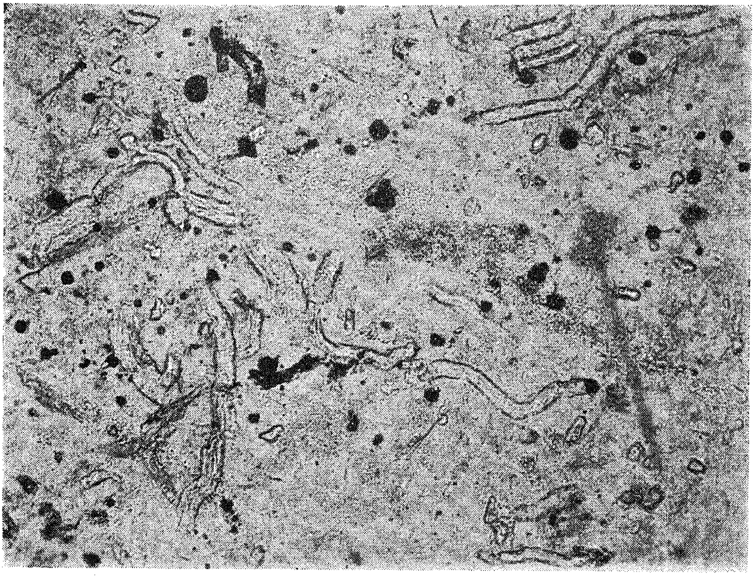


FIG. 10. Blue-green algae (resembling living *Mactis* or *Microcoleus*) from basal Huronian rocks of Michigan. Enlarged 190 diameters. Photograph from Dr. Gruner.

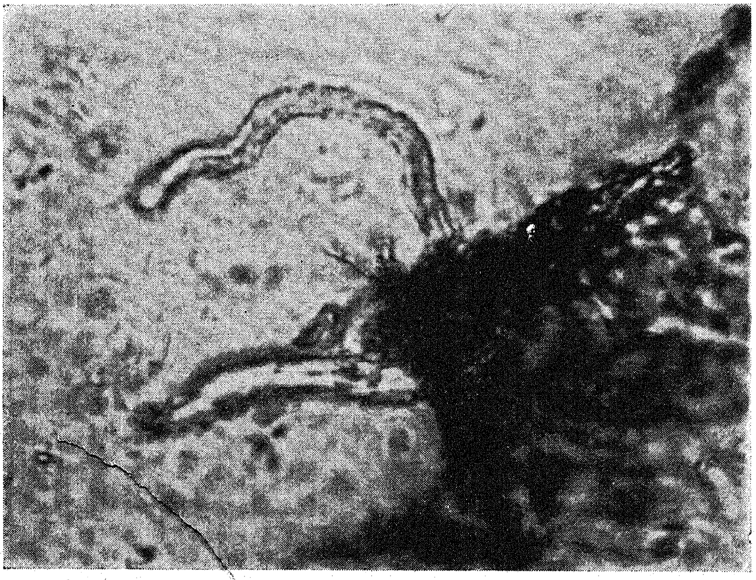


FIG. 11. Blue-green algae from Upper Huronian of Michigan. Enlarged 2200 diameters. Photograph from Dr. Gruner.

than one part of iron to the million, and sea water is also deficient in iron. Certain swamp waters, especially those associated with peat bogs, have been found to contain as much as forty-seven to

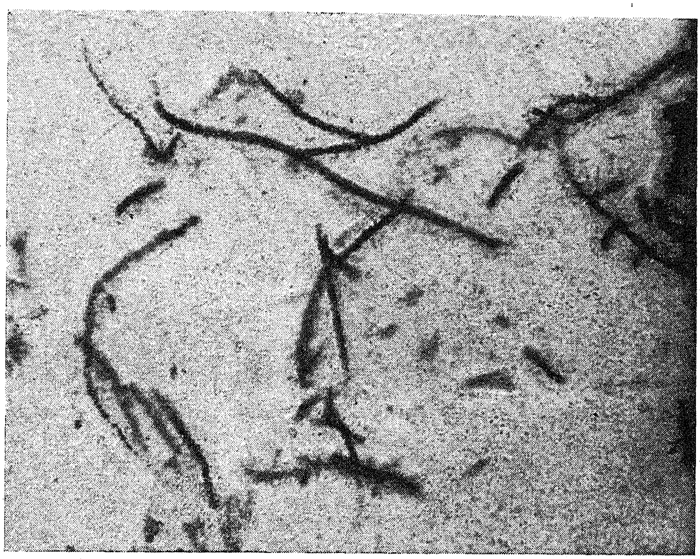


FIG. 12. Iron bacteria, resembling living *Chlamydothrix*, from Upper Huronian chert of Michigan. Enlarged 310 diameters. Photograph from Dr. Gruner.

sixty-one parts of iron per million, and it is noteworthy that waters containing much iron are always rich in organic matter.

The manner in which the iron was taken from the water evidently involved certain intricate chemical processes that are not yet well understood, though it is presumed that the bacteria, acting on the disintegrating organic matter, liberated certain acids that precipitated the iron in a form insoluble in water, and it fell to the bottom of the body of water, where it gradually accumulated into beds often of wide extent and thickness. Whether these beds of iron were accumulated in fresh or salt waters is not certainly known, though there seems no good reason why it might not have been in fresh waters. It is regarded as reasonably certain, however, that these deposits of iron were accumulated under humid, sub-tropical or tropical climatic conditions.

Although these organisms and the various actions and reactions

they set up are but imperfectly known, the important fact to be borne in mind is that such organisms were actually present at a time so vastly long ago as the Huronian period, which a glance at the time scale on page 18 will show, is in the lower part of the Proterozoic era. They well deserve to be called the dawn plants.

Although there is as yet very little direct evidence to show the extent to which plants had then developed into different forms and kinds, there is reason to believe that they had become enormously abundant, and there is also reason to suppose that they had early begun to split up into various kinds and types, more or less in response to their surroundings. It has long been noted that when plants or animals become vastly numerous, and their struggle for food and life becomes acute, some develop qualities or structures that better fit them for the struggle, and they forge ahead. This condition was presumably reached among these early forms, and, we may conclude that, sooner or later, some of them developed structures or habits that gave them an advantage over their fellows. That this is a reasonable conclusion is shown by the fact that as plant life progressed to the point where their remains came to be freely preserved in the rocks they show such marked differences as to suggest that they may have been splitting up and changing during this long twilight period.

With this slight lifting of the veil, affording a momentary glimpse of the plant life of Huronian time, we come, perhaps after some millions of years, to the overlying Keweenawan rocks for the next rift in the dark clouds. In the rocks of this period, in addition to the bacteria already mentioned (page 37), there are found the remains of a number of algae, or sea-weeds, that had developed the power of extracting limestone (calcium carbonate) from the water in which they lived and building up peculiar layers and forms around their various parts.

There is a large group of algae now living in salt or brackish waters, known as the calcareous algae, that take lime from the water and form it about themselves in a great variety of shapes. In many cases they resemble corals, and for this reason they are sometimes called the coralline algae. They play quite an important part in building up beds of limestone.

There is another group of algae living in the fresh water of lakes and ponds that produce flat discs or button-shaped masses

of limestone, often called water biscuits, which are from a few inches to a foot or more in diameter. This limestone-selecting habit of the algae has come down through the ages very little changed, as we find plants that had this power at many other points in the long journey from the Algonkian to the present. They have undoubtedly been of great importance in building up vast beds of limestone.

A few years ago Doctor Walcott described no less than a dozen forms of these supposed lime-secreting algae from the Algonkian (Keweenawan) rocks of Montana. They are found over an area of more than six thousand square miles, and through beds many thousands of feet in thickness. They are believed to have lived in shallow, warm, fresh water, where they may occur singly, or more frequently they formed great masses, or "reefs," as they are called, in which respect they resembled the so-called coral reefs, known in many later formations, and, indeed, they may have had the habit of certain of the living corals.

These Algonkian algae are still very imperfectly known, and Doctor Walcott states that "all of the genera and species are based on the variation in form, as it is impossible with the data now available to determine the genera and species of the *Cyanophyceae* (blue-green algae) that built up the widely different forms. They all agree in not having the structure of the higher algae. All appear to have been deposited in successive layers, the inner and older layers serving as a foundation in which the younger filaments grew in variously arranged forms. In the absence of the identification of the actual algae that built up the structure found in the fossil state, a purely artificial classification has been adopted."

In the article in which these supposed algae are described, Doctor Walcott has given a great number of illustrations showing the various forms they assume. The appearance of these concentric layers is sometimes very well brought out in some naturally weathered specimens picked up on the surface of the ground, or the same effect is produced when a freshly broken fragment is etched with acid, that is, the limestone is dissolved away, leaving the layers as irregular ridges. Such a naturally weathered example of one of the most abundant forms is shown in *Figure* 13. This

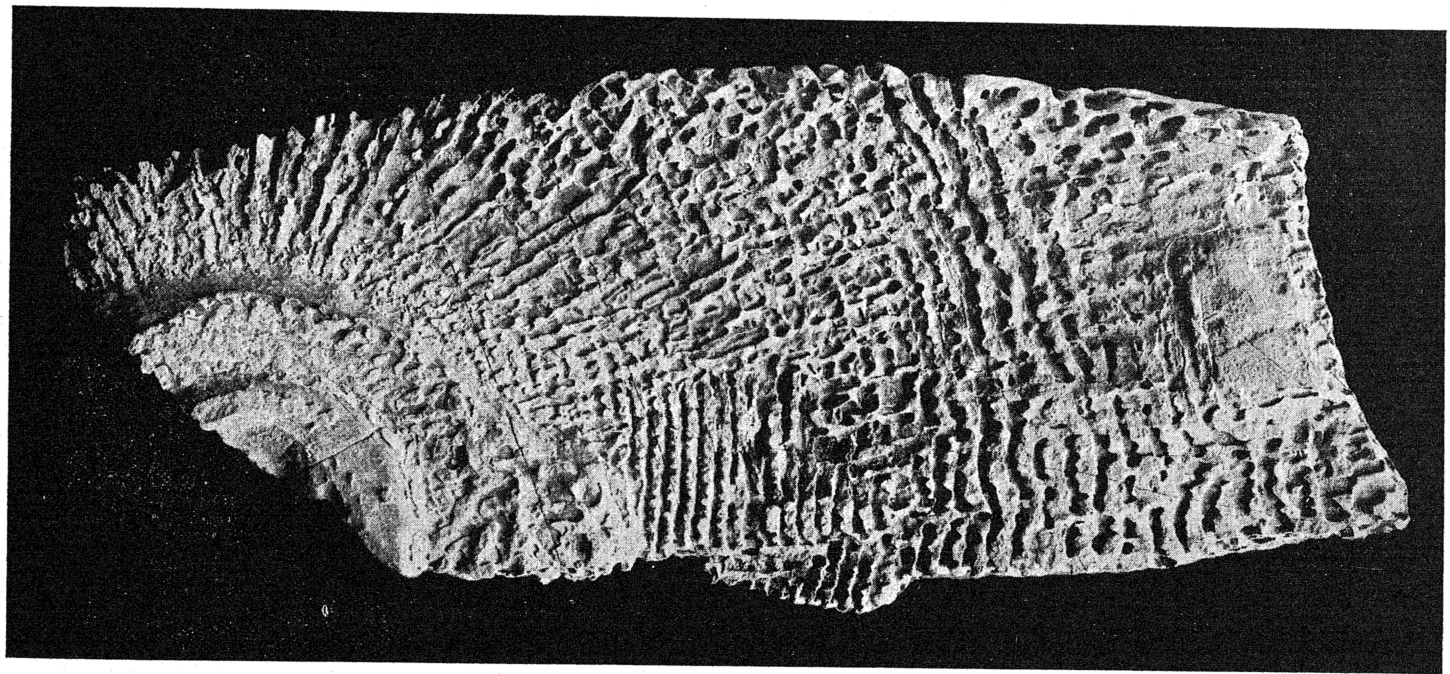


FIG. 13. Large frond of supposed alga (*Newlandia frondosa*) from Algonkian rocks of Montana. About one-half natural size. After Walcott.

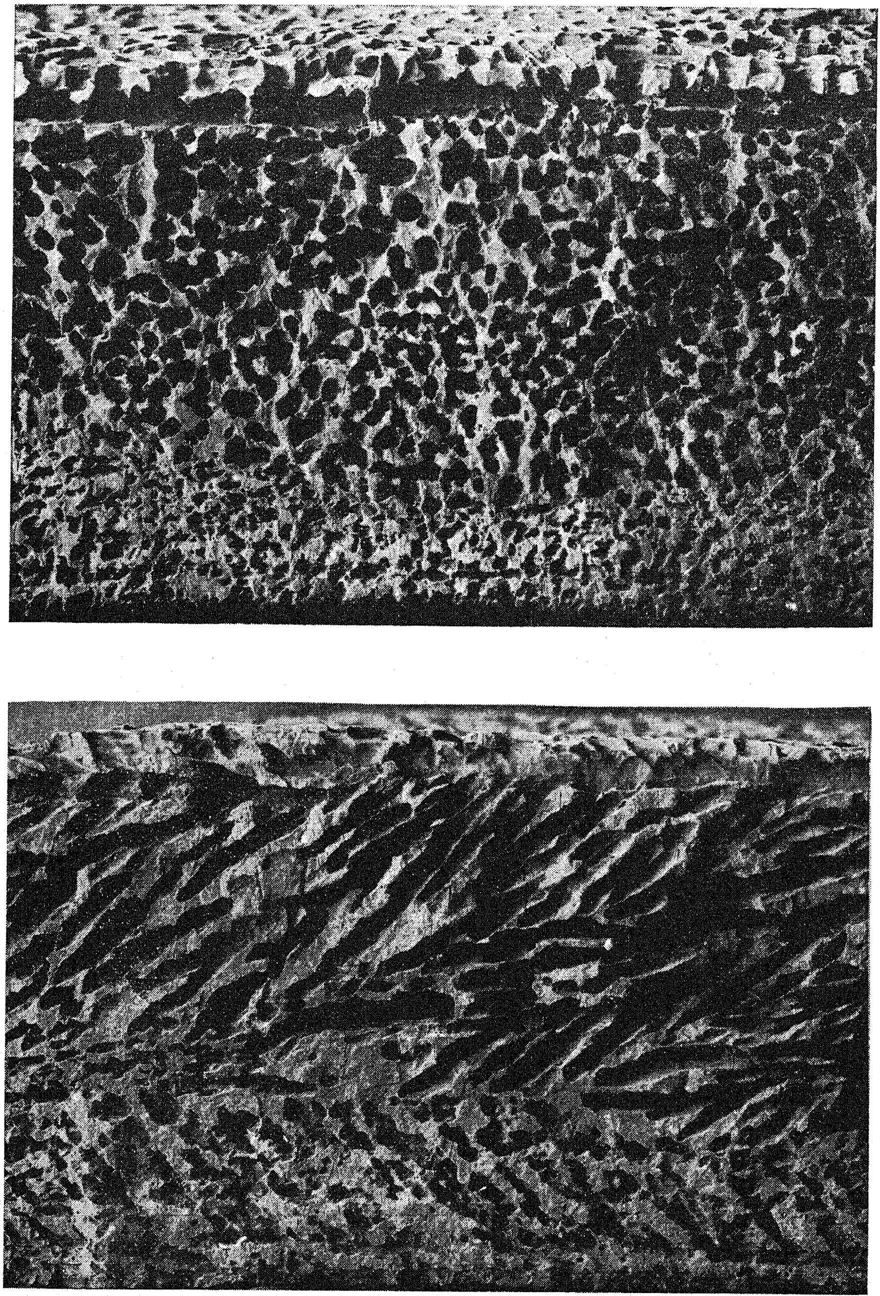


FIG. 14. Supposed Algonkian alga (*Camasia spongiosa*) from Montana. *Upper.* Vertical section showing vesicular character. *Lower.* Section at right angle to *upper* showing tubular openings. Natural size. After Walcott.

is called *Newlandia concentrica*. Another form, known as *Camasia spongiosa*, is seen in *Figure* 14.

A chain of algal cells, multiplied about 1400 times, associated with *Camasia spongiosa*, is shown in *Figure* 15 *c*, *d*, and a small group of round cells, multiplied about 350 times, may be seen in *Figure* 15 *a*, *b*. The relation between these seemingly different

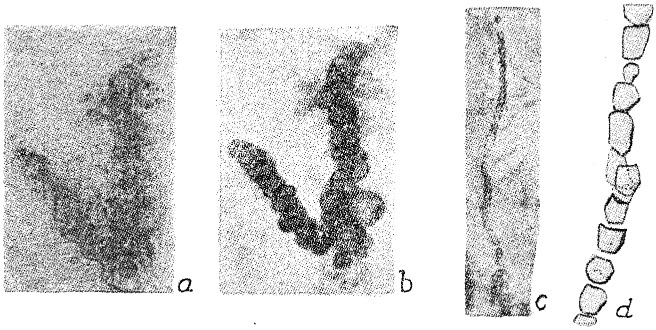


FIG. 15. Algal cells associated with *Camasia spongiosa* from Algonkian rocks of Montana. *a*, *b*. Group of rounded cells, enlarged about 350 times. *c*, *d*. Chain of cells, enlarged 1400 times. After Walcott.

kinds of algal cells is very obscure, and we must await further study before they can be properly evaluated.

Remains of reef-forming organisms similar to those just described are known to exist in much later Cambrian rocks in Montana, but they have not yet been adequately studied.

When it is recalled that probably more than half of geologic time had passed by the end of Proterozoic time, it seems rather remarkable that plant life had then apparently made so little progress—that is, according to present knowledge. It is not unlikely, however, that there was really a very considerable diversity of form and habit developed at this time, and that the foundation was being laid for what appears to be some of the sudden advances made in later times, but this is, of course, only speculation at present. It is also probable that very much more will be learned about these early forms since it has been found that such high powers of the microscope are required for their study.

Recently a very important announcement has been made, that, if fully substantiated, would go far to establish the presence of

a land flora millions of years earlier than was previously supposed. Dr. R. Kräusel, of Berlin, has described a small woody stem, from the pre-Cambrian rocks of Bohemia, to which he has given the name *Archaeoxylon*, which signifies "ancient wood." It shows what seem to be wood cells or tracheids, marked with small round pits or pores. This of course suggests a gymnospermous structure, but Doctor Kräusel states that it can hardly belong to this group and compares it with certain forms belonging to the *Psilophytales*, a group of vascular plants that first appear in lower Devonian rocks. (See p. 18.) As the specimen is not very well preserved, it may not have been correctly interpreted, and it is best to wait for further confirmation before accepting it at its apparent face value.

Chapter V

PLANTS OF THE CAMBRIAN, ORDOVICIAN, AND SILURIAN PERIODS

IT is almost a misnomer to speak of the flora of the Cambrian, Ordovician, and Silurian periods, for so very little is actually known about the plants that lived during these times that an account of them can hardly be made to cover a page. There were certainly the "Dark Ages" of plant life, at least so far as our knowledge of it is concerned. This is rather remarkable, too, when it is known that during these three periods a thickness of more than twenty miles of sandstone, limestone and shale was deposited in different parts of the world. All this of course took a very long time; in fact it is thought by many geologists that the time was as long as, if not indeed longer than, all the time that has since passed.

One reason why our knowledge of the plants of these periods is so limited, is the fact that most of these great thicknesses of beds were deposited in salt water and would be very unlikely to contain plants that lived on the land, if there had been such plants. Beds that are deposited on the land—so-called continental deposits—mainly in fresh water, are best fitted to preserve the plants of the time, but if there were such deposits during these three periods, they must have been washed away or are now buried so deeply beneath the later rocks or under the oceans that they cannot now be seen.

The only plants that are known with certainty to have lived during Cambrian, Ordovician, or Silurian times were sea-weeds (algae). Of these perhaps as many as a hundred kinds have been described, together with a number of others that are very questionable, some of which are undoubtedly the tracks and trails of animals, or are simply markings caused by the waves rolling over shallow sand or mud flats and are not plants at all.

A glimpse of the evident profusion of algal life in Middle Cambrian time has resulted from Dr. C. D. Walcott's study of material from the so-called Burgess shale, near the town of Field,

British Columbia. This locality is also remarkable for the number and diversity of animal forms and their unusually perfect state of preservation, no less than ninety-four genera and more than one hundred and fifty species having been described, all from a body of shale fifteen by one hundred feet in area and seven feet in thickness.

Concerning the mode of preservation Doctor Walcott wrote as follows: "The algal remains usually occur as shiny black films on the surface of the hard silicious shale; this form of preservation is the same as for the medusae, sponges, annelids, crustaceans, etc., except that the algae were evidently more gelatinous and membranous; it appears to have made little difference whether the fossil was a flat, thin frond, a sphere, or a thick-bodied crustacean; all alike have been reduced to films of varying thickness without greatly distorting the original outline and arrangement of parts.

"The mucuous or gelatinous mass of algae; the sponges and spicules of sponges; the flesh of annelids; the test and body of crustaceans, have all been replaced by a shiny black carbonaceous-appearing silicious film."

As none of these Burgess shale algae show a point of attachment, it is assumed that they were floating forms, or in any event that they had floated into the quiet waters of the shallow bay, to be covered by the fine muds and preserved very much like dried herbarium specimens. No fruiting organs have been found, and indeed in only rare instances is the cellular structure preserved, thus leaving only the size and shape to serve as the basis for comparing them with living forms. It is obvious that this is a very insecure foundation for the recognition of possible kinship with living algae, and the resemblances can hardly be more than accidental or superficial, but as they are obviously algae, they may be taken for what they are worth. To the end that they may be known, Doctor Walcott has established seven form genera, to which are referred some twenty nominal species. It is thought possible that three families may be represented, namely the blue-green algae (*Cyanophyceae*), the green algae (*Chlorophyceae*), and the red algae (*Rhodophyceae*). Several of the more striking forms are shown in the *Figures* 16 and 17.

Some of these ancient sea-weeds were of gigantic size, such as

Nematophycus of the upper Silurian, which had stems nearly two feet in diameter, and doubtless hundreds of feet long. This

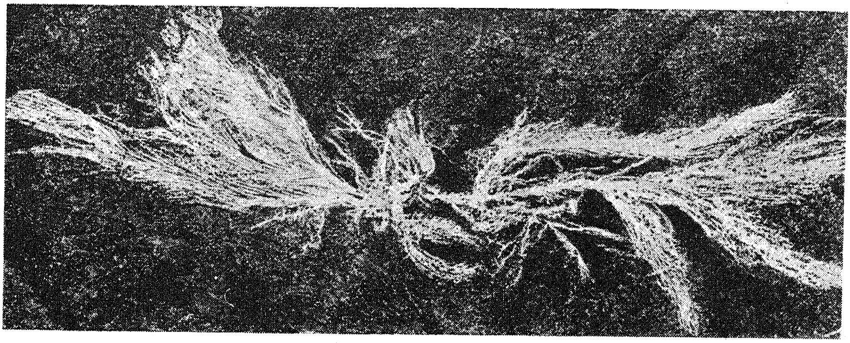


FIG. 16. Supposed blue-green alga (*Marpolia spissa*) from Middle Cambrian rocks (Burgess shale) of British Columbia. Twice natural size. After Walcott.

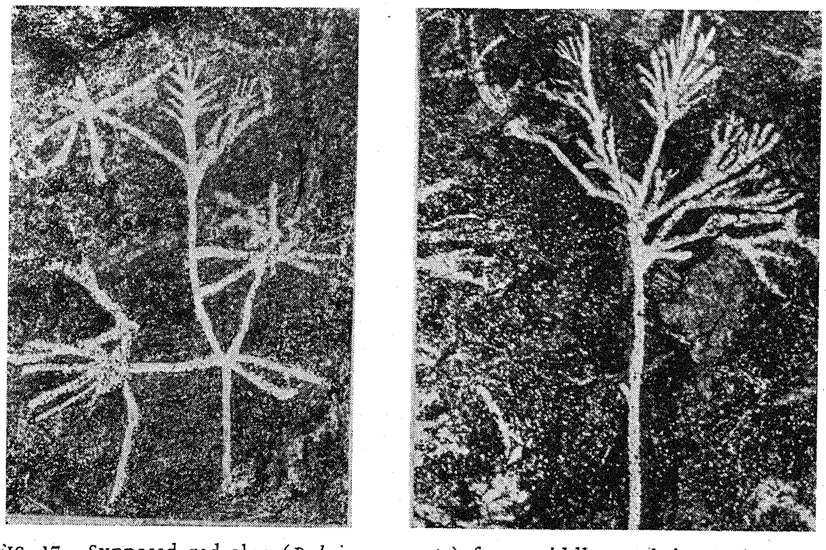


FIG. 17. Supposed red alga (*Dalyia racemata*) from Middle Cambrian rocks (Burgess shale) of British Columbia, enlarged about 3 times. After Walcott.

plant was evidently abundant in the Devonian, and will be more fully described in the next chapter. If the evidence, such as we have, has been correctly interpreted, the algae of these ages had already developed so far as to establish several of the great

groups into which the living sea-weeds are divided. But the story of the plant life of those distant years is almost a sealed book.

It is now very well agreed that all the land plants that later clothed the earth were developed from plants that lived in the water (algae). This is well shown by the fact that many of them still retain characters, especially in their methods of reproduction, that are directly inherited from these remote sea-weed ancestors. The steps, as well as the time, when plants came up out of the sea and took up a life on the land are not known, and may never be fully known, but it is very reasonable to suppose that it may well have been long before we have any positive evidence. Land plants seem to spring so suddenly into existence in the Devonian age, with such a variety of kinds and such complexity of structure that it must mean that they had left the sea long before our fossil records show it. Some students have even suggested that there was probably a land flora in existence during the larger part of the ages we are considering, but this is largely speculation at present.

The animal life during the Cambrian, Ordovician, and Silurian periods was wonderfully developed and diversified. Many of the great groups of invertebrate as well as vertebrate animals now living had their beginning at this time, and several important groups not only had their origin, but they waxed mighty and had died out to the last one before the close. As directly or indirectly the food of animals is supplied by plants, it is not only fair to suppose that there was abundant plant life but also that it was highly developed, though still mainly confined to the water.

There is almost as much uncertainty concerning the advent of the land animals as there is regarding the coming of the land plants. Like the plants, they too must have come up out of the sea. No land animals are known for Cambrian time, nor is there reliable evidence for their presence during the Ordovician, and apparently it was not until the upper Silurian that the first air-breathing animals made their appearance. These are the scorpions, which are close of kin to the spiders. They have come down to the present day with little essential change and are abundant in many parts of the world.

Some years ago Dr. T. G. Halle, the eminent Swedish paleobotanist, described a fragment of a supposed land plant under the

name *Psilophyton hedei*, from the upper Silurian rocks of Gothland. It was found in marine beds in association with two species of simple animals known as graptolites. The specimen was a branched fragment of a "stem" about two inches in length and one-twelfth of an inch in diameter, provided with minute projections of "spines" that are not unlike the so-called spines of *Psilophyton*, to be described later. Figures of this organism, some of them enlarged several times to bring out the details as well as possible, were shown to two expert students of the graptolites, and neither one could note any valid reason for excluding it from that group. Of course it may be a plant. The best that can be said now is that the evidence is not convincing.

Chapter VI

DEVONIAN TIME AND THE EARLIEST CERTAINLY KNOWN LAND FLORA

JUST as written or recorded human history was preceded by a long, slowly clearing twilight of myth and superstition, during which man was preparing for the conquest of the world, so, for countless ages, plants were undergoing a long, slow process of evolution and development that was to fit them for the greater part they were to play in the grand economy of Nature. During this ages-long twilight stage—a far longer time than has since passed—some plants were made ready in Devonian time, so far as the records show, to take a notable advancing step—one of the most important and far-reaching steps ever taken by plants: they left the water and began to live on the land; they began their conquest of the solid earth.

As we have seen in the preceding pages, up to the beginning of Devonian time plant life was almost entirely confined to the water. From their beginning as minute, single-celled plants, or as a simple chain of minute cells not unlike a string of tiny beads, they had developed into a great variety of kinds showing a great increase in size, some of them, indeed, being of gigantic dimensions. It seems altogether possible, not to say probable, that some of these algae had left the water and become adapted to life on the land before Devonian time, but if this is so we have thus far been able to find comparatively little satisfactory evidence for it. So far as we now know, land plants first came into existence in early Devonian time. From the fact that these earliest land plants show such differences in kind, and such an advanced stage of development on the pathway toward their living descendants, it seems almost certain that they must have lived on the land for a very considerable time before we find the remains preserved in the rocks. It may be that their remains are buried in rocks now covered by the sea, or by other later rocks, and so are forever lost.

Although we do not now know, and, indeed, may never know, the exact steps taken by plants when they left the water for a life

on the land, it may be supposed to have been somewhat like this: Early Devonian time was a period of flat land surfaces and low coasts whose bays were bordered by broad marshes, which were covered and uncovered at regular intervals by the tides. Some of the algae are known to have developed thin, flat, somewhat leaf-like organs, which were not able to stand up when removed from the water. As they were exposed to the air when left by the out-going tides, these minute leaf-life organs were rolled up, but if not killed by too long exposure to the air, they would be restored to their normal form when again covered by the water. Gradually some of them were less and less affected by the absence of water, and became more and more able to live for longer and longer periods of time in the air, until finally they were able to live alto-gether on the land. At first they lay flat on the ground or rocks. They had no roots, for previously they had drawn all their nour-ishment from the water in which they floated and had no need of roots. Their leaves were either spine-like or very small, slender, and delicately thin. At first their leaves were so thin that they could absorb the carbonic acid gas to serve as plant food directly from the air, but later they developed stomata or breathing pores, which are the means of communication between the air and the in-terior of the plant, though they still drew much of their food from the water. To support their weight in air a strengthened cuticle, which was later developed into a complicated cortex or so-called bark, was made to serve until a woody axis should be fully pro-duced by their descendants. There is evidence to show that at first they sprawled or clambered on the ground or over other plants of their kind. When they had become fully adjusted to life on the land, their progress seems to have been astonishingly rapid, and in a very short time we find that they established several of the very different great groups that have come down to the pres-ent day. There is one very significant point which shows clearly the kinship of these early Devonian land plants with their aquatic ancestors, and this is that certain of the important reproduction steps can only take place in the presence of water, a fact that is equally true of many of their descendants living at the present time.

We may now leave this fascinating but more or less unfruitful speculation and turn to the actual plants as we find them pre-

served in the early rocks. If we could have walked abroad in this far-off Devonian time, we who are fairly familiar with the plants living today would have found the plants strange, crude, unnatural, and altogether forbidding. It seems probable, from the study of the remains found, that the plants were not so numerous, and did not so nearly cover the ground as they do in many places today, but their apparent scarcity is perhaps due to the imperfection of the record they left.

One of the most interesting of these plants, but one about which full information is still lacking, is known as *Psilophyton*, which means "naked plant," in allusion to its naked, leafless stems. It was discovered many years ago in eastern Canada by the late Sir William Dawson, and the same or similar forms have since been found in Maine, Scotland, Bohemia, Germany and elsewhere. A restoration of *Psilophyton*, as it was thought to have been by Dawson, is shown in *Figure* 18.

It was a plant about two feet in height, with a cylindrical woody stem half an inch or less in diameter, growing erect from a tangled mat of creeping stems (rhizomes) which had tiny rootlets (rhizoids), whose obvious function was to absorb water. The upright stems were forked, and the young branches were coiled up (circinate) at the tips, as are the growing tips in many living ferns. These stems are provided with what at first sight appear to be ugly spines or prickles, though there are gradations from stems with strongly marked spines to those that are nearly or quite naked, the latter, under the name *Dawsonites*, being sometimes regarded as belonging to a different plant. These spines or prickles have usually been regarded as rudimentary leaves, but recently some exceptionally well preserved specimens have been studied with the result that they are now believed to be merely outgrowths or protuberances of the stem, and not foliar organs. The stems of these plants also showed the presence of stomata, or breathing pores, which establish communication between the interior of the plant and the outer air. The fruiting organs consist of naked oval spore-cases, usually borne in pairs on slender curved pedicels, either lateral or terminal on the smaller branches. The spores, so far as can be made out, are all of one kind. (See *Figure* 18 *a*.)

Dawson's restoration was based on fragmentary material, and some later students have suspected that he probably made use of

two or more distinct forms, but it is now conceded that he was essentially correct in his conclusions. Unfortunately but little is yet known regarding the internal structure of *Psilophyton*, as it is usually found only as an impression in the rocks, but from what little has been made out, it appears to be closely related in its anatomy to *Asteroxylon*, which will be described on a later page.

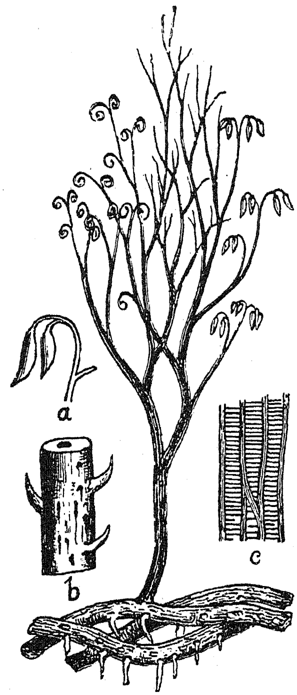


FIG. 18. Early Devonian land plant (*Psilophyton princeps*) as restored by Dawson. *a*. Branch with spore cases, enlarged. *b*. Stem enlarged showing "spines." *c*. Wood cells of stem showing ladder-shaped thickenings. After Dawson.

Recently some interesting little plants that are evidently very closely related to, or perhaps identical with, those last considered have been discovered in Aberdeenshire, Scotland. They are known as *Rhynia*, a name derived from that of the locality where they were found. The deposit containing them, evidently an ancient peat bed, is about eight feet in thickness and includes several layers made up almost entirely of these plants. The whole deposit

has been silicified, that is, with all the parts changed to silica, and hence it is possible to cut thin sections through the plants in all directions and to study them under the microscope as completely as it would be if they were still living. There are two species, based on size, both with erect cylindrical stems, those of the smaller (*Rhynia gwynne-vaughani*, restored in *Figure* 19 *a*) attained a height of some eight inches and a diameter from that of a small lead pencil down to that of the lead in the pencil, while the larger form (*Rhynia major*, restored in *Figure* 19 *b*) was nearly or quite three times this size. They were closely crowded together and had neither roots nor leaves, the upright stems coming, as in *Psilophyton*, from branched underground rhizomes, which were attached to the peaty soil by minute rootlets. The internal structure of the upright stems is beautifully preserved, and is seen to consist of a solid central cylinder made up of long wood cells (tracheids), which are marked on their inner walls by thick rings. Outside of this is a layer of thin-walled cells, and then an outer bark or cortex made up of thick-walled cells. The stems also show the presence of scattered stomata.

The reproductive organs of *Rhynia* have not been found in actual connection with the plants, but they are so closely associated with the stems as to leave no reasonable doubt as to their really belonging to them. The spore-cases were long cylindrical sacs, usually pointed, and borne at the ends of the branches, generally solitary though occasionally in pairs, and sometimes the tip of the branch was merely hollowed out to contain the spores. The spores, which were very numerous, were sometimes free, and sometimes united in fours; they are typically fern-like in appearance.

Obviously there are many points of agreement between *Rhynia* and *Psilophyton* and, as hinted above, some students incline to regard them as generically identical.

In the uppermost beds containing *Rhynia* there were found the remains of another curious little plant that has been called *Asteroxylon*, which means "star-wood." A restoration of this plant is shown in *Figure* 20 *a*.

Asteroxylon was a little taller than *Rhynia* and had a thicker stem, which was completely covered with small, narrow leaves and suggests at once some of the living club-mosses (*Lycopo-*

FIG. 19. Early vascular land plants from the Devonian of Scotland. *a. Rhynia gwynne-vaughani. b. Rhynia major.* Restored by Kidston and Lange.

dium). It had neither roots nor rootlets, the underground portions of the stem apparently taking the place of roots. The woody elements (vascular system) in the stem differ markedly from those of *Rhynia*, being arranged somewhat in the form of a star (whence, of course, its name) and having spiral thickenings on the inside walls of the wood cells. The fruiting organs are not certainly known. *Asteroxylon* is evidently closely related to *Rhynia* and may have come from the same stock, but it is much further advanced. It is supposed to have given rise to, or at least to be related to, the club-mosses (*Lycopodium*) and to the ferns.

There is still another strange plant known as *Hornea* found in the Rhynie beds. It was a small, simple plant, suggesting at first sight a small edition of one of the species of *Rhynia*, but instead of having the stem-like rhizome of the latter, the upright stems sprang from a series of little tuber-like thickenings resembling roughly the so-called corms of certain flowering plants. Its fruit-organs were simpler than in *Rhynia*, for instead of a more or less distinct spore-case, the tips of the branches were enlarged to hold the spores. This shows, as Doctor Scott has said, "that in these old and simple plants the sporangium (spore-case) was not a distinct organ, but just the end of a branch modified for spore-bearing purposes." There was also an arrangement of tissues in the spore-case that suggests a similar appearing organ in certain living mosses. *Hornea* is shown in restoration in *Figure* 20 *b*.

Sir William Dawson discovered another curious plant in the lower Devonian rocks of Nova Scotia, to which he gave the name *Arthrostigma* (see *Figure* 21); it has since been found in Scotland and Norway. It is much larger than either of the other Devonian plants thus far considered. It has furrowed forking stems an inch or more in diameter and bears numerous scattered ugly hooked or sometimes straight spines. For a long time these spines were thought to have functioned as rudimentary leaves, but in view of their similarity to the spines of *Psilophyton*, it is now believed by many that they are only outgrowths or protuberances from the stem. The reproductive organs of *Arthrostigma* are unknown.

There are a number of other Devonian plants that appear more or less closely related to those enumerated above, but as most of them are imperfectly known it is best to pass them by. It remains

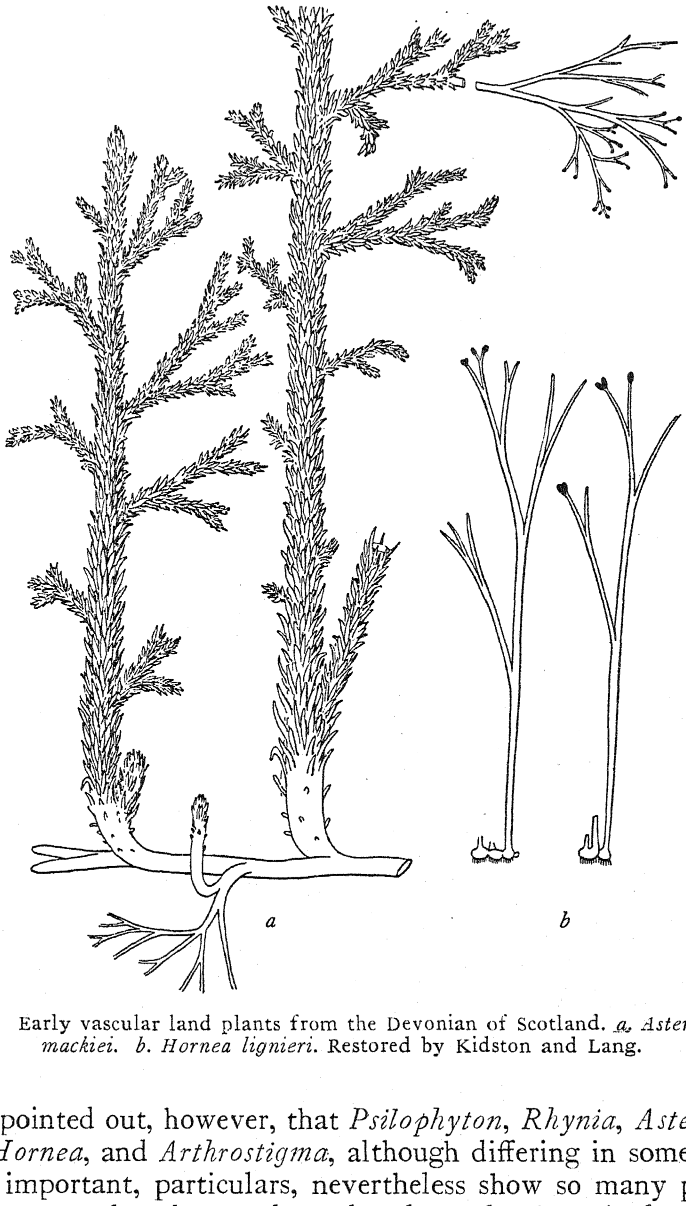


FIG. 20. Early vascular land plants from the Devonian of Scotland. *a. Asteroxylon mackiei.* *b. Hornea lignieri.* Restored by Kidston and Lang.

to be pointed out, however, that *Psilophyton*, *Rhynia*, *Asteroxylon*, *Hornea*, and *Arthrostigma*, although differing in some, and often important, particulars, nevertheless show so many points of agreement that they are best placed together in a single group. They cannot possibly be referred to any other group into which

plants, either fossil or living, are now divided. This group is called the *Psilophytales*, and includes two families, the *Rhyniaceae* and the *Asteroxylaceae*. These are the oldest known land

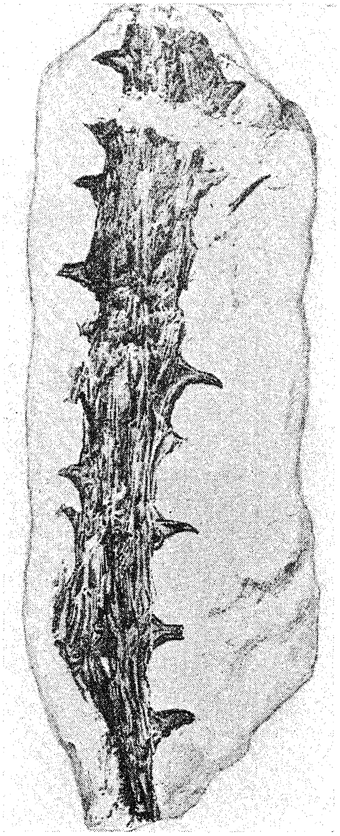


FIG. 21. Stem of early Devonian land plant (*Arthrostigma gracile*). After Kidston.

plants in which a vascular system has been observed, which marks an extremely important advance. It is possible that the beginning of such a vascular system had been inaugurated in certain algae before they left the water, but of this there is at present little direct evidence.[1]

[1] Although the most interesting remains found in the Rhynie chert bed are of course the vascular plants described above, it is also worthy of note that an abundance of lower plants were present, such as bacteria, algae of small types, as

Here we may pause for a moment to consider the lessons to be drawn from the study of the *Psilophytales*. These plants obviously afford a glimpse of certain fundamental evolutionary processes. In addition to developing a vascular system, which not only enabled the stems to assume and maintain an upright position but afforded a "pipe line" to conduct water, they laid the foundation of a root system to absorb water and nourishment; they developed stomata or breathing pores, to maintain communication between the interior of the plant and the outer air; they made a fumbling attempt to produce leaves; and finally they modified the tips of their stems to make them serve as spore-cases. Not all of these features were new, but they were newly adapted to a life on the land.

Differences have arisen among students as to the interpretation of the evolutionary status of this interesting group of plants. As we have seen, there is at least a suggestion that one of them (*Hornea*) may have been the foundation that led the way to the mosses, but the evidence is far from conclusive. There is also the possibility that another (*Asteroxylon*) may have given rise to the lycopods, but this also is unsettled. On the whole, however, the most convincing evidence points to their having been the stock leading to the ferns. Quite clearly the *Psilophytales* were synthetic plants—that is, they were a sort of "melting pot" out of which various types could have come, though the steps by which this took place are not yet clear. It is worthy of note in this connection that no fern or fern-like foliage has thus far been found among the lower Devonian plants, though there are some stems or rachises, as well as some imperfectly known fruiting organs, that are probably referable to the ancestral stock of the ferns; but proof is still lacking.

Before leaving these earlier floras attention may be called to an interesting plant found first in the middle Devonian rocks of Scotland, and later in those of Bohemia and western Norway. It

well as not less than fifteen apparently distinct forms of fungi. The latter are slender, mainly non-septate filaments (hyphae) or threads found mostly in decaying parts of the vascular plants, but also ramifying throughout the mass of peat. They were evidently saprophytic, that is, they derived their sustenance from decaying parts of plant structures, as do hundreds of similar living forms, the important point being their association with this earliest known land flora.

These organisms are fully described and figured by Kidston and Lang, *Trans. Roy. Soc.*, Edinburgh, Vol. LII, pt. 4, pp. 885-902, pls. I-X, 1921.

is best known as *Palaeopitys milleri*, though sometimes assigned to the genera *Lycopodites* or *Thursophyton*. It had a cylindrical, irregularly branching stem, half an inch or more in diameter, bearing small, stiff, sharp-pointed leaves. It was first described from impressions, but recently specimens have been found with the internal structure preserved, showing it to have a highly organized anatomy, and indicating its reference to the gymnosperms. However, if the published figures usually given of a fertile branch really belong to this plant, it seems more likely to be a primitive lycopod rather than in line with the gymnosperms. The main point of interest lies in the fact that a plant with such advanced anatomical characters should have been established at this early time.

As already pointed out, there is abundant, though not always conclusive evidence of the presence of primitive ferns in the early parts of the Devonian, but in the middle and upper Devonian the evidence becomes much clearer. Some of these early forms were evidently in the line that culminated in the living ferns, though in most of them the organs of reproduction were not preserved or have not been recognized, and hence their position is more or less uncertain. They had the foliage of ferns or fern-like plants, but as they were evidently not a very conspicuous element of the Devonian flora, most of them may be passed over without further comment. There is, however, one important fern that should be mentioned. It is known as *Archaeopteris*, and is widely distributed, having been found in eastern North America, the Arctic regions, and possibly China. It was a large, rather coarse fern with leaves (fronds) sometimes three feet in length. The leaves were compound—that is, cut up into smaller divisions, which had entire (unbroken) margins—or more frequently they were variously cut into small teeth or narrow masses of long, thread-like segments. The strong veins arise near the point of attachment of the leaflets, and were once or twice forked. The reproductive organs were large spore cases, single or grouped in twos and threes, borne on the same fronds as the sterile portions. A figure of a well known species (*Archaeopteris jacksoni*) from Maine is shown in *Figure* 22. At one time *Archaeopteris* was thought to be one of the ancestors of the seed-ferns, which became such an important element in the Carboniferous flora, but there

is little valid reason for this view, and it must be considered as probably in line with the true ferns.

FIG. 22. *Archaeopteris jacksoni*, a supposed true fern from the Devonian rocks of Maine. *a*, *b*. Pinnules showing nervation. After Dawson.

In upper Devonian time, although there is no evidence of marked climatic change from that of the preceding earlier Devonian, the plants show very important advances, not only by an increase in the number of kinds but by a distinct advance in their early steps in the long march toward the present flora. It would seem that it must have taken a very long time to develop this upper Devonian flora from the preceding known floras, but

what is more probable is that they actually had their origin in early Devonian time, although their remains have not yet been discovered, or if found, are so fragmentary that their affinities have not been recognized. In any event there was here a great foreshadowing of the rich and varied flora of the succeeding Carboniferous time.

Many years ago a remarkable fossil tree was found in upper Devonian rocks near Naples, New York. This tree, which is now preserved in the State Museum at Albany, combines characters that, in the succeeding Carboniferous time, marked two very distinct groups, namely, *Lepidodendron* and *Sigillaria.* It was about a foot in diameter at the enlarged base, and the portion recovered was about eighteen feet long, but was probably at least twice this height when living; at the top it is now reduced to a width of only three inches. The leaf was narrow and sharp-pointed, with a broad conical base, and evidently remained attached to the trunk for a very long time. When the leaf finally came off it left behind a broad scar corresponding to the leaf base, and it is these scars and their arrangement that show the kinship of the tree with the two kinds of plants above mentioned. At the base of the trunk the leaf-scars are arranged on ribs in narrow vertical rows, which is a character of some kinds of *Sigillaria*, but in the upper portion of the tree the ribs die out and the scars are more scattered and arranged more or less clearly in a spiral, as in *Lepidodendron.*

This tree, which is perhaps the tallest tree that existed before Carboniferous time, has been given the somewhat formidable name *Protolepidodendron primarium.* A restoration of it is shown in *Figure* 23, with figures about natural size of a leaf and the two kinds of leaf-scars. Remains of the same or closely related trees have been found in Pennsylvania, England, Norway, Bohemia, and Germany.

Some fifty years ago a number of fossil tree trunks were found in upper Devonian rocks near the little town of Gilboa, in eastern New York. They were studied and described by Sir William Dawson, who recognizes two species, which were placed in *Psaronius*, a well known genus of ancient tree ferns of which mention will be made later. In the years that followed the original discovery a few additional pieces or parts of trunks were found,

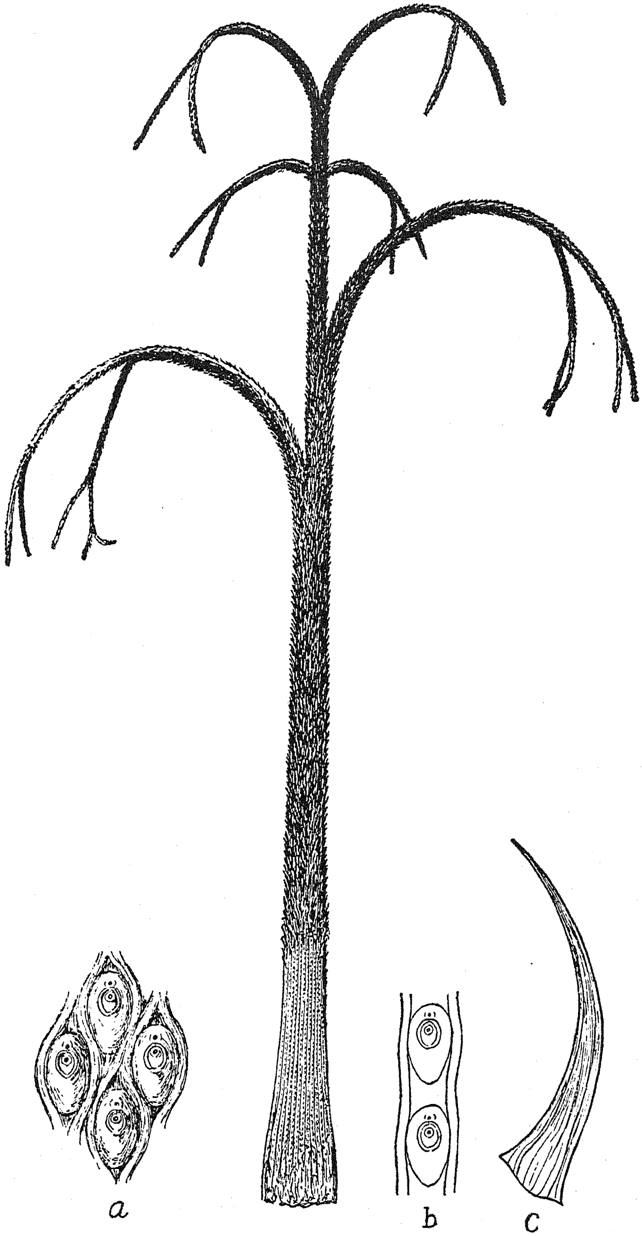


FIG. 23. Fossil tree (*Protolepidodendron primarium*) from Upper Devonian rocks near Naples, New York. About 1/20 natural size. *a. Lepidodendron*-like leaf scars; *b. Sigillaria*-like leaf scars; *c.* leaf, natural size. Restoration by Berry.

but it was not until 1920 that trunks were found in such numbers that the deposit may be called a veritable fossil forest. In that year the city of New York, in extending its water supply, began the building of a dam on Schoharie Creek at Gilboa (which, incidentally, will drown the village), and in blasting out the rocks for the dam hundreds of these trunks were uncovered, in one case as many as eighteen being taken from an area of fifty feet square. The trunks were found at two levels about one hundred feet apart. The State Museum at Albany has procured about forty of these stumps and trunks and has built a museum group of what is perhaps the oldest fossil forest in the world. (See *Frontispiece.*)

They are mainly upright stumps standing in what was the soil in which they grew, with only an occasional one that was prostrate when it was fossilized. Most of them are broken off at a height of only four or five feet, and are thought to have been from thirty to forty feet tall when living. They range in diameter from one or two to three and a half feet and are conspicuously bulged at the base; in no trunk was the internal woody structure so preserved that it could be studied. In the rocks surrounding the trunks were found the leaves and fruiting parts, and although they were not found actually connected to the trunks there can be no doubt that they really belong to them.

A restoration of one of these trees by Miss Winifred Goldring, who has recently given a most interesting account of them, is shown in *Figure* 24. It shows the curious bulging base and the slender, tapering trunk, with its furrowed or checked bark and its crown of huge spreading leaves, some of them six feet long, made up of innumerable little leaflets. But, strangest of all, it was found that this tree actually bore seeds, thus placing it with the seed-ferns, which became such an important element in the Carboniferous flora (see p. 77). The seeds were borne in pairs at the ends of modified leaflets, and there were sometimes clusters of two or three pairs of seeds close together. The seed was about one-fourth of an inch in length and was enclosed in an outer husk or cupule, which completely covered it up; it was in fact very much like the seeds of *Lygenopteris*, the best known of the Carboniferous seed-ferns.

These trees have now been given the name *Eospermatopteris*,

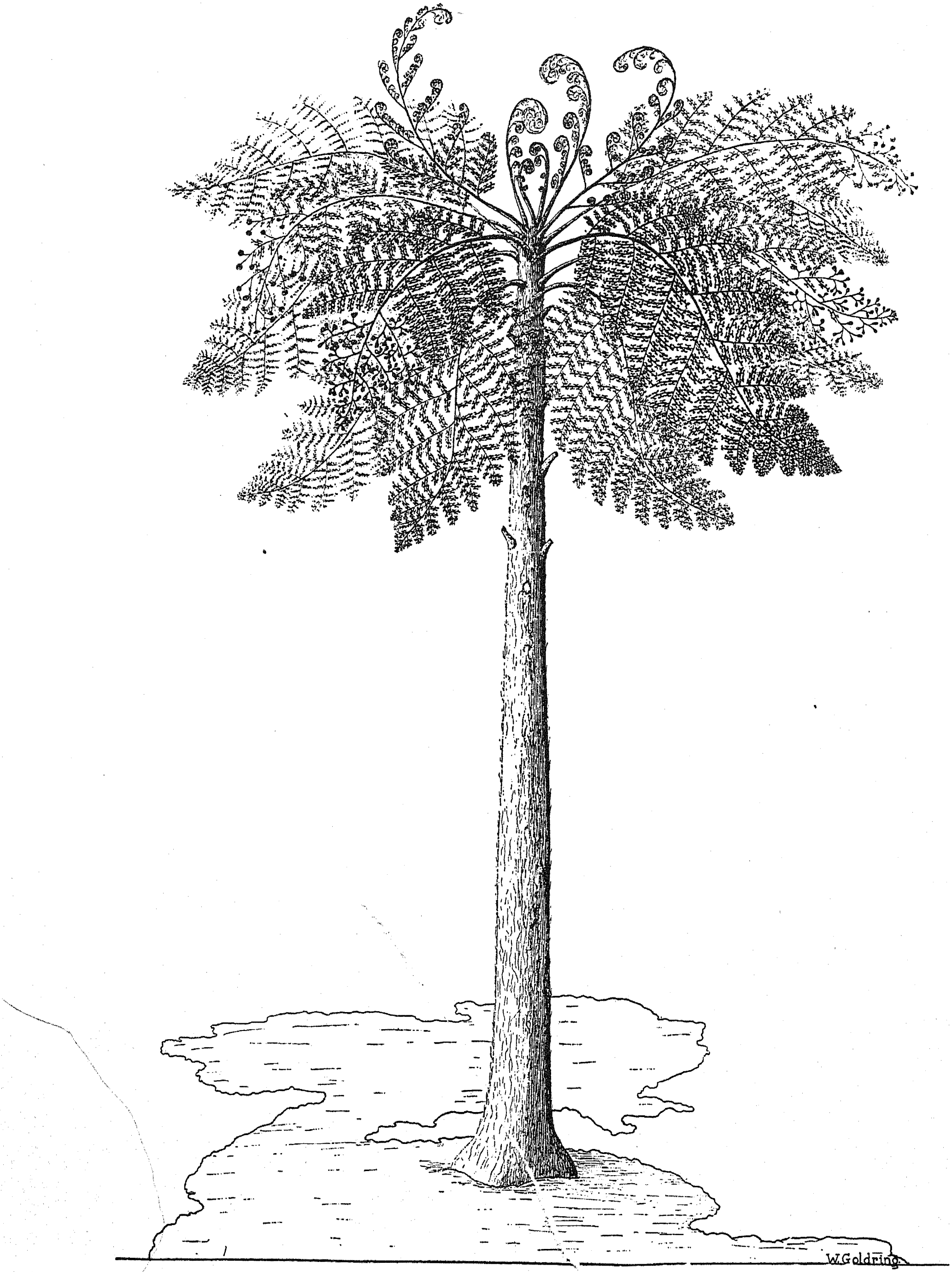


FIG. 24. Restoration of seed-fern (*Eospermatopteris textilis*) from Upper Devonian rocks, Gilboa, New York. Restoration by Miss Goldring.

which means the "dawn seed-fern." It had long been suspected that the seed-ferns must have been in existence during Devonian time, but now the actual proof has been supplied.

There are a number of other plants or groups of plants that had their beginning in Devonian time and are important from the evolutionary standpoint, but which are so imperfectly known that it is almost impossible to gain a clear idea of their appearance. For instance, there is a single species of *Sphenophyllum* found in the rocks of Bear Island in the Arctic Ocean. It had ribbed stems and small, very narrow, highly divided leaves, and it is the forerunner of a large group that flourished in the Carboniferous. It will be more fully described when that flora is considered.

Another plant, known as *Hyenia*, comes from the Devonian rocks of western Norway. It had leafy shoots that radiate in tufts from a stem or rhizome, and it bore minute leaves, in whorls of four or six at indistinct nodes. *Pseudobornia* is the name given an interesting plant also from Bear Island. It was a horsetail-like plant about ten feet in height and several inches in diameter, with short nodes bearing finely divided leaves in whorls of four. The fructification was in the form of a long catkin-like body, sometimes over a foot in length, with the spore-cases in the angle of the modified leaves (sporophylls). It is a very rare plant.

Although there may be some doubt as to the gymnospermous character of *Palaeopitys*, described above from the middle Devonian, there is none at all concerning the presence of highly organized members of this group in the upper Devonian. One of the most striking of these is known as *Callixylon*, a genus based on silicified trunks, first made known from the Donetz Basin, in southern Russia, and since recognized in Ohio and elsewhere. When thin slices of the wood of *Callixylon* are viewed under the microscope it is seen that the walls of the secondary wood cells are provided with groups of peculiar markings known as bordered pits. These bordered pits, which are more or less characteristic of all coniferous woods, are really thin points or pits in the walls of the cells, and each usually coincides with a similar pit in the wall of the neighboring cell. They are generally circular and arranged in one or more vertical rows, but they may be six-sided and cover the entire wall more or less completely, as in the wood

of the living *Araucaria*, the Norfolk Island pine. In *Callixylon*, however, the bordered pits are arranged in groups of a dozen or more, with a clear space between each group. (See *Figure* 25.) Nothing is known with certainty regarding the foliage or fruiting

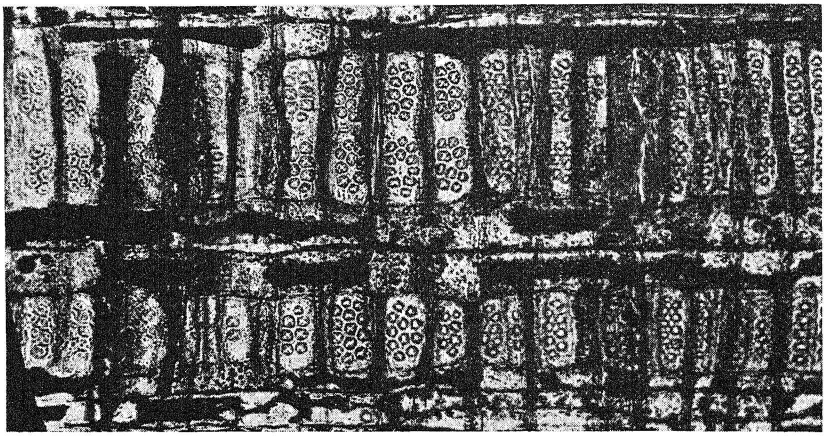


FIG. 25. Radial section of wood cells of *Callixylon oweni* from Devonian of Indiana, showing bordered pits in groups. Enlarged 150 diameters. Photograph from Dr. Wieland.

characters of this tree, but it is clearly a highly specialized type which survived into Carboniferous time and then disappeared.

There were other trees in the upper Devonian, known from petrified trunks, some of which are two feet or more in diameter. They are called *Dadoxylon* or *Araucarioxylon*, and their wood cells are characterized by the six-sided pits of the type just mentioned. They are found in many parts of the world and indicate the existence of several different species. They are thought by some to be ancestral stock that gave rise to the living *Araucarias*, but by others they are supposed to be the woody trunks of *Cordaites*, a group of trees that became of special importance during Carboniferous time.

A very strange plant known as *Nematophycus* was first described in 1856, by Sir William Dawson from some large silicified trunks found in Lower and Middle Devonian rocks of Canada. It was thought that these trunks showed certain woody elements (tracheids), the cells of which exhibited pits and spiral

thickenings and hence were supposed by Dawson to be trunks of coniferous trees. They were given the name *Prototaxites* and were thought to be allied to the living *Taxus*, or the yews.

Some years later Carruthers, in England, studied some of the original material from Canada, as well as a number of other European forms, and reached the conclusion that instead of being a coniferous tree, it was really a gigantic fossil seaweed, and this view has been abundantly confirmed by many other students, and it is now considered as an alga, for which the name *Nematophycus* was adopted.

As now interpreted these trunks, some of which are two or three feet in diameter, are made up of somewhat loosely compacted longitudinal tubes, which may be of two sizes, some large, others small and thread-like. In some forms the tubes appear to be disposed in what appear to be growth rings, thus simulating the arrangement of the woody elements in exogenous trunks. The length of these trunks is unknown, and as neither foliage nor organs of reproduction are certainly known, the relationship of the plant to living algae is somewhat uncertain, though, all things considered, it seems most probable that it is nearest to the brown algae (*Phaeophyceae*). No less than eight nominal species are recognized, ranging in age from upper Silurian through the Devonian. They are found in New York, Ohio and Canada, and in Wales, England and Germany.

A very curious and unusual occurrence of a species of *Nematophycus* was recorded a few years ago in connection with the silicified peat bed at Rhynie in Scotland. It is difficult to account for the presence of a marine alga in a fresh-water marsh two hundred miles from the nearest salt water, but there it was! There is evidently much more to be known about the life history of *Nematophycus* than has yet been discovered.

In closing this short account of the more conspicuous plants of Devonian time, a word may be said regarding their possible place of origin, their wide distribution, and the probable climatic conditions under which they grew. The exact place or places where the Devonian flora first left the sea and took up life on the land is not known and indeed may never be known. Some facts seem to indicate that this transition may have been in eastern North America, where they are most numerously represented,

while other facts seem to indicate that it may have been in the Arctic regions, whence they were free to spread to lands to the southward. Their known distribution includes Greenland, Spitzbergen and Bear Island in the Arctic regions, the eastern provinces of Canada, the States of Maine, New York, Ohio, Kentucky, and other states, eastern Russia, Norway, Scotland, Ireland, Bohemia, and Germany in Europe, and Australia, in the Southern Hemisphere. There is also some evidence, though it is not yet conclusive, that they may have extended well into the Antarctic region. The distribution of the same or of closely related plants over this vast area can only mean that the climate of the world was then remarkably uniform and that it changed little during the whole of Devonian time. There was evidently an abundance of moisture, and the temperature must have been relatively high. There is no evidence that frosts occurred.

Chapter VII

THE PLANTS OF CARBONIFEROUS TIME

THE word Carboniferous, which means carbon-carrying, is used to designate the geologic period during which our most valuable deposits of coal were formed. The change in plant life from Devonian to Carboniferous was not an abrupt one, in fact, if an observer could have been on the ground at that time, it is doubtful whether he would have noticed that a change was taking place. It was much like journeying from a northern to a southern clime, where, one after another, the northern plants give place to the southern plants so gradually as to pass almost unnoticed, though at the end of the journey the change would be complete. But instead of taking place in a few hours, the change from the Devonian to the Carboniferous flora may have taken a million years.

Many of the plant types that clothed the land in late Devonian time undoubtedly continued with little change into early Carboniferous time, and thus formed the nucleus for the marvellous change and expansion that came in the later Carboniferous flora, for, when taken by and large, the vegetation of this time was in many respects one of the most wonderful and luxuriant, though not the most varied, floras the world has known. The old Devonian earth floor was warped and folded and formed shallow troughs and basins but little above sea level, for the early Carboniferous was a time of the spread of the sea over the land.

Although several thousand species of Carboniferous plants have already been found, described, and named, it is reasonably certain that the number actually found fossil is only a small part of those that lived in that olden time but were not preserved. In many parts of the world new and interesting plants are continually being brought to light, and so the work is going on in the effort to piece together parts of the great picture of past plant life. Unfortunately, many of the pieces are so fragmentary that we are still unable to fill out the picture as completely as we could wish, so the present chapter will be an account of only the more

conspicuous and better known of the plants of Carboniferous time.

Ferns. The Carboniferous period has often been called the Age of Ferns, because plants of this group, or at least plants with the foliage supposed to be exclusively that of ferns, far outnumbered all their associates. They are the commonest fossils found in these rocks, often occurring in great numbers, especially in the shales associated with the coal beds, and many of them are of large size. Then suddenly, some twenty years ago, it was discovered that many, perhaps most of these supposed ferns, although bearing the fern-like foliage, had developed the seed-bearing habit; they were not true ferns at all. These are now called the seed-ferns (*Pteridosperms*), and will be described later.

There are, however, many real ferns in the Carboniferous, as proved not only by foliage, but by the fruiting organs, by which all ferns, both fossil and living, are classified. Probably many have noticed small brownish spots on the under sides of the leaves of living ferns, such, for example, as the common house plant known as the Boston fern, which, on the part of those not well informed, are sometimes regarded as the work of insects. These spots contain the fruiting organs, and are known as fruit-dots (sori). *Figure* 26 *a* shows the under side of a leaflet (pinnule) of the Christmas fern, and this brings out clearly the regular size and spacing of the fruit-dots, while *Figure* 26 *b* shows two fruit-dots enlarged about ten times. There is seen a thin shield-shaped covering (indusium) beneath which are many little spore cases (sporangia) each of which contains hundreds of spores. A single spore case still further magnified is seen in *Figure* 26 *c*. There is a thickened elastic ring of cells (annulus) around the middle of the spore case, which, as it dries at maturity, springs backward and splits the wall on the opposite side and permits the escape of the spores. (See *Figure* 26 *d*.) The size, position, and covering (if any) of the fruit-dots, and the presence or absence of the elastic ring of cells in the spore case, as well as the size, shape, and ornamentation of the spores, are all made more or less use of in the classification of living ferns, and the same holds good for fossil ferns whenever these features can be made out. In fossil ferns where the fruiting organs have not been found the only thing that can be done is to identify the foliage as closely as

possible with others in which these organs are known, or, when this fails, to bring together all with a similar kind of foliage into so-called "form genera," or genera of convenience, and await hopefully the finding of more complete specimens.

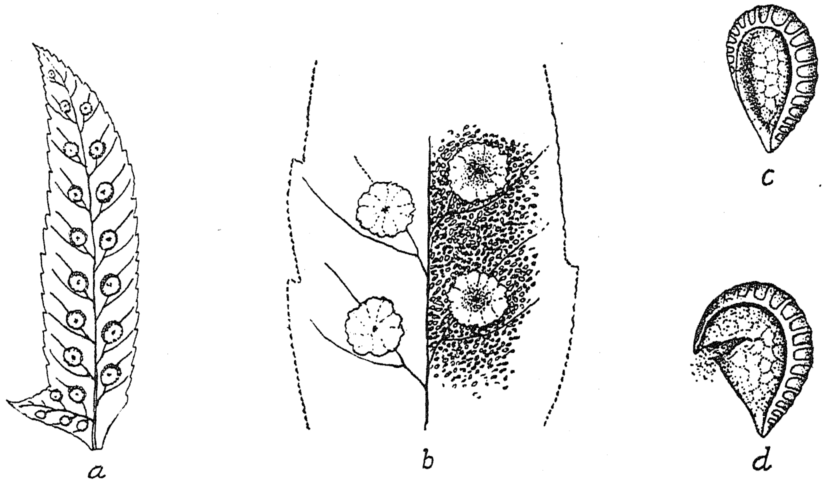


FIG. 26. Fruit of living Christmas fern (*Polystichum acrostichoides*). *a.* Pinnule showing fruit dots (sori), natural size; *b.* two mature fruit dots, enlarged 10 times; *c.* spore case (sporangium) showing annulus, enlarged 90 times; *d.* spore case split to discharge spores, enlarged 90 times.

In this connection it may be of interest to describe the manner in which ferns are reproduced, as it is more or less typical of the method in the other fern allies. As already mentioned, the fine, microscopic, dust-like spores are produced in special organs (sporangia), usually aggregated in groups (sori) on the under side of the fern leaves, and often in almost incredible numbers, a single plant producing from 20,000,000 to perhaps 50,000,000. When these spores germinate, however, they do not develop directly into a plant like the one that bore them, as do the seeds of flowering plants; they develop first a delicate little flat cushion of cells, called the prothallium, which is from one-tenth to (exceptionally) a third of an inch in length. On the under side of the prothallium two sorts of organs are produced, which correspond to the male and female organs, and known respectively as the antheridia and archegonia.

The antheridia (male) are little, low, chimney-like organs,

with walls of a single layer of cells, and containing numbers of spirally coiled threads, which escape by the rupture of the cell walls. These coiled filaments (called antherozoids), which possess the power of locomotion, swim about freely in the moisture that must always be present.

The archegonia (female) are also low, rounded masses of tissue, with an outer layer of cells and a large central cell, which soon divides into two parts. The lower part, at first the larger, develops into a roundish cell, which corresponds to the egg of an animal. The upper part of the central cell develops between the cells that form the neck of the archegonium into a canal that is filled with a sort of mucilage, which finally swells up, forces the cells of the neck apart, flows out, and serves to attract and hold the coiled male filaments (the antherozoids), some of which finally force their way into the neck and into the egg cell, thus fertilizing it. After fertilization the neck of the archegonium closes, and the egg cell (now called the oospore) increases in size, and finally develops into a fern plant like that which produced the original spores.

This somewhat complicated process of fertilization as developed in the ferns is essentially the same as that seen in the various fern allies—the horsetails, lycopods, selaginellas, and quillworts—though in some it is further complicated by having the male and female organs developed from spores of different size, the larger, called macrospores, producing only the female organs, and the others from small so-called microspores, which give rise to the male organs. Thus the process of fertilization is so closely adjusted that the absence of adequate moisture at the critical time when the male filaments (antherozoids) are mature, would cause speedy death. It was probably just this condition that caused the decline of these groups which rose to such prominence during Paleozoic time. As we shall see, it was the lepidodendrons, sigillarias, and calamites that formed the splendid forests of Carboniferous time. They lived in swamps, where the atmosphere was supposedly steaming with moisture, all of which furnished ideal conditions for the complicated mechanism of fertilization, which we know was similar to that above described, for many Paleozoic prothallia have been found. That of *Lepidostrobus veltheimianus* (the cone of *Lepidodendron*), for instance,

is a perfectly typical female organ (archegonium), which is precisely similar to that of certain lycopods living today.

In later Paleozoic time the swamps dried up, the moisture-laden atmosphere cleared, and the ideal conditions required for the fertilization of these plants gradually passed away, and so they slowly faded from the picture, to be replaced by a few more hardy smaller types which have survived to the present time.

With this considerable but essential digression, we may now return to the consideration of the true ferns of the Carboniferous period, of which there were a considerable number remaining even after the removal of the seed-ferns. They fall roughly into two groups, the tree-ferns, and the *Primofilices* or so-called ancient or early ferns.

Our knowledge of the early ferns, which ranged in age from Upper Devonian to Permian time, is based very largely on the anatomy of the stems and petioles, with only sporadic hints regarding the foliage and fruiting characters, hence information regarding their appearance when living is somewhat vague. They were evidently small plants of various habit, some having long, creeping rootstocks, and others having a short, stout, upright stem, which was crowded with leaf bases. Probably none exceeded a few feet in height. They have been divided into two groups or families, the botryopterids and the zygopterids.

The botryopterids (*Botryopteriaceae*) include three or four genera, all based on stem anatomy, with fruiting organs known also in one genus. The stem was rather simple, consisting of a single vascular cylinder in which the wood cells (tracheids) were provided with ladder-shaped or reticulate thickenings on the inner walls. With the exception of certain small scale-like or "false leaves" (aphlebiae) found on the stem, or on the otherwise naked rachises in a few species, no foliage has been definitely connected with them. Where known the small pear-shaped spore-cases are borne in clusters of two to six on the naked ultimate divisions of compound fronds. There is evidently a more or less remote degree of kinship between the botryopterids and the living flowering ferns (*Osmundaceae*), adder's tongue ferns (*Ophioglossaceae*), and possibly the elephant ferns (*Marattiaceae*).

The zygopterids (*Zygopteraceae*) are based almost entirely on the structure of the petioles, and beyond the fact that the

leaves were arranged in two or four rows on the stems—an arrangement unknown in recent ferns—little is known about either foliage or fruit.

The Paleozoic tree ferns, however, are much better known. They had trunks two feet or more in diameter and were sixty or seventy feet in height, with a splendid crown of large, spreading compound fronds (leaves) at the summit, and must have rivalled in impressiveness of appearance the living tree-ferns. When the structure of these stems is preserved, as it usually is by silification, they are referred to the genus *Psaronius*. They are among the earliest fossil plants that attracted attention and when cut and polished they made decorative objects that were called "starling stones" (Staarsteine), from the fancied resemblance of their markings to the spotted plumage of the starling.

The foliage where it has been connected with the *Psaronius* stems, is found to be of the *Pecopteris* type, which is one of the commonest and most familiar of the fern leaves found in the shales of the Carboniferous coal mines. (See *Figure* 27.) The fructification of these pecopteroid fronds is of several kinds, which have led to the establishment of several genera. Instead of having the spore cases free, as they are in most living ferns, they are more or less confluent or cemented together in groups of five to eight to form rings, or are sausage-shaped and placed in two continuous rows on each side of the mid-vein of the leaflets; they opened by pores or slits to discharge the spores. In other genera the spore cases, which are arranged in groups of four or five, are pendent and are cemented together only at the base. A marked peculiarity of the spore cases is the complete or nearly complete absence of the so-called annulus, which is described on page 72.

The character of the fructification indicates that the Paleozoic tree-ferns are most closely related to the living elephant ferns (*Marattiaceae*), a group of about five genera and slightly over a hundred species, now widely spread throughout the tropics of both the Old and the New World. From their imposing size and appearance in Paleozoic time they have gradually dwindled in size until they are no longer tree-ferns; they are now small ferns only a few feet high, with clustered fronds.

FIG. 27. A pecopteroid fern (*Pecopteris dentata*) from the Carboniferous of Missouri. Photograph from specimen in National Museum.

THE SEED-FERNS

It came as a great surprise when it was found, a few years ago, that what everyone had always supposed were perfectly good

ferns had already developed the seed-bearing habit. It had long been taken for granted that the flowering plants were so eminently successful because they "discovered" and perfected the method of reproduction by seeds; and so in large measure they were, but they were not the first to discover that method, for these fern-like plants had hit upon the plan, had waxed mighty for a time, and had passed off the stage some millions of years before the first flowering plants appeared, at least before they appeared in force.

The discovery that these plants with fern-like foliage bore real seeds led to another interesting revelation. Various loose, unattached seeds are very commonly found in rocks containing these coal plants. A few of these seeds had been quite clearly fixed as having been borne by *Cordaites* or similar plants; others suggested the seeds of the maidenhair trees, or the seeds of cycads, but most of them were of unknown origin. Their resemblance to seeds that have actually been connected with the seed-ferns makes it now seem more than probable that many of them were borne by seed-ferns, although only a few have as yet been connected with them.

As the seed-bearing habit in these ancient plants with a fern-like foliage is so interesting and important, a rather full description will be given of the one that is best known. This plant is called *Lyginodendron* (or *Lyginopteris*), and is shown in restoration in *Figure* 28. Fossil plant material is often so broken and fragmentary that it frequently happens that two or more parts of a plant are found and described at different times, perhaps by different persons, before it is discovered that all the fragments belong to a single kind of plant. This has been particularly true of *Lyginodendron*, the roots of which were first known under the name of *Kaloxylon*, the persistent petioles of the leaves as *Rachiopteris*, the foliage as *Sphenopteris*, the pollen-sacs as *Crossotheca*, and the seeds as *Lyginostoma*, the whole making up the plant now known as *Lyginodendron*.

Lyginodendron, a fairly common plant in the English coal measures, was what may be called a little tree-fern in habit. It had a slender stem, two inches or less in diameter, and was probably unable to stand alone, but had to depend more or less on its neighbors for support. At the lower part of the stem it had what

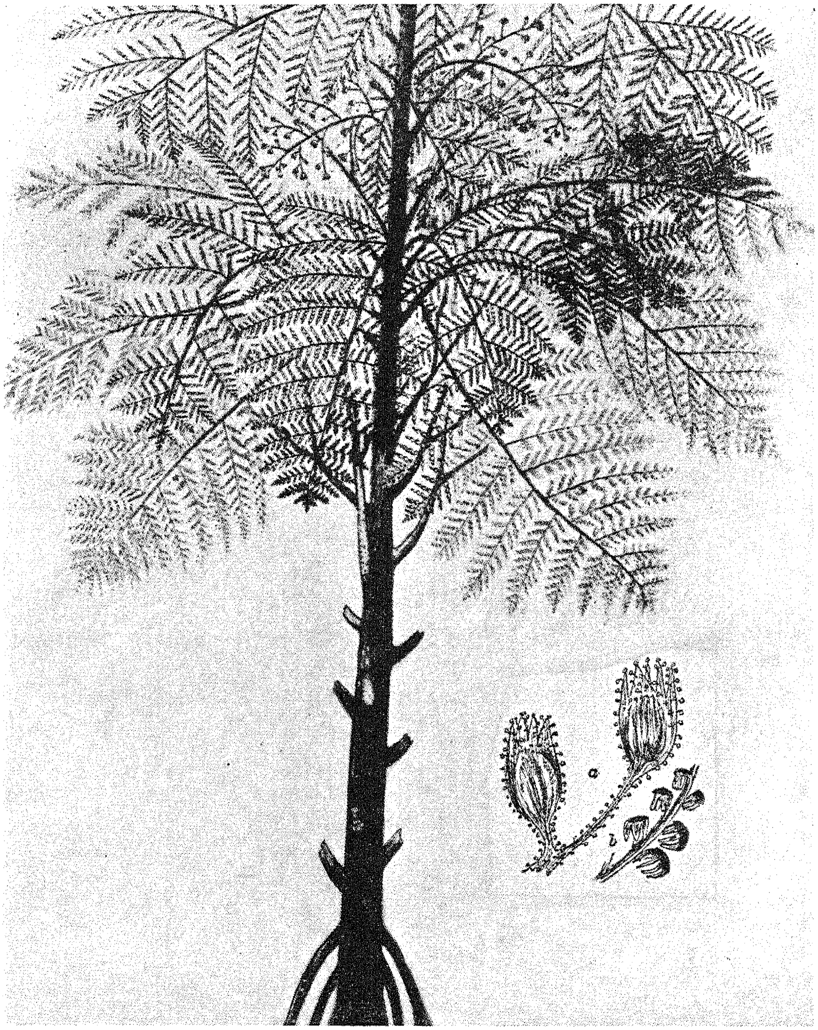


FIG. 28. Restoration of Carboniferous seed-fern (*Lyginodendron oldhamium*) showing stem, roots, foliage, and seeds much reduced. Modified from Berry. *a.* Seeds in cupules, studded with glands; *b.* male organs, showing discs and pollen sacs. Nearly twice natural size. After Scott.

are called adventitious roots, that is, roots that originated well above the soil in which it grew, and that branched only after they had reached downward into the soil. These roots helped to hold the plant upright in soft, loose soil, as do similar roots in the Indian corn. The whole stem and the leaves are provided with spines, as well as with numerous small, usually stalked glands, which may have secreted honey, though of course this is not known. The leaves are arranged spirally on the stem and form a large graceful crown near the top. Some of the individual leaves were more than three feet in length, and were divided into numerous small leaflets, which are thick and incurved at the edges, suggesting that the plant may have grown in a salt swamp. The petioles are always forked, and these remained on the stem for a long time, perhaps throughout the life of the plant. The internal structure of the roots, stems, and petioles is well known, but it need only be mentioned that the stem has elements that show its kinship with both ferns and the cycads.

The seed of *Lyginodendron* is a little barrel-shaped body about a quarter of an inch long, closely enclosed in a sort of cupule or envelope, not unlike the inflated calyx of the ground cherry (*Physalis*), or a hazelnut in its husk or involucre. Two of these seeds are shown nearly twice natural size in *Figure* 28 *a*, with one side of the cupule cut away to show the seed more plainly. The husk or cupule, as well as the stalk or stem on which the seeds are borne, is thickly studded with little stalked glands already mentioned as covering the stems and petioles. It was the similarity of these glands that first suggested that the seeds belonged to *Lyginodendron*, and this was further confirmed when it was found that the structure of the pedicels of the seeds was identical with that bearing the leaflets. The seed itself was very complex and highly organized. It had a distinct seed-coat, which was closely joined to the central part of the seed-body, but open at the top. The upper part of the central seed-body was surrounded by a cavity or pollen chamber, and in some especially well-preserved specimens, numerous pollen grains have been found. This pollen chamber was a device whereby the pollen could with certainty be brought into the proper position to insure the fertilization of the seed.

The exact manner in which the seeds were borne on the frond

is not known, but their resemblance to certain other forms which have been found attached makes it seem more than probable that they were borne on naked portions of the frond that were especially devoted to the production of seed, just as the central portion of the frond of one of our cinnamon ferns (*Osmunda*) is given over to the production of its fruit.

Curiously enough an embryo or immature plantlet has never been found in a seed of *Lyginodendron*, or for that matter in any other Paleozoic seed. This probably means that the actual fertilization and formation of the embryo did not take place until long after the seed had fallen from the plant, perhaps not until it was buried in the soil. This delayed growth is not unknown in certain living plants—for example the cycads.

There are a number of other seed-ferns besides *Lyginodendron* that bore the seeds on a naked part of the frond, and there were others that bore them on the tips of ordinary foliage leaves or fronds, and in some the foliage pinnules were slightly reduced near the seeds. Such a plant, known as *Aneimites fertilis*, once lived in West Virginia. A fragment—natural size—is shown in *Figure* 29 *a*. It was a delicate, probably weak little plant with

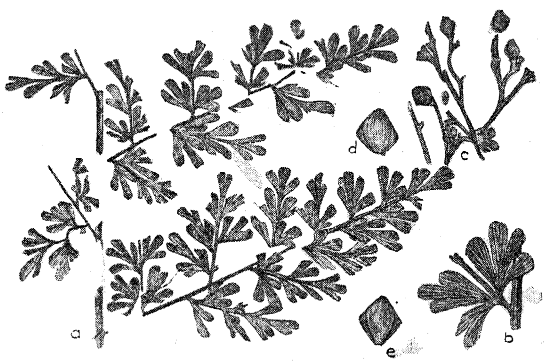


FIG. 29. Seed-fern (*Aneimites fertilis*) from Carboniferous of West Virginia. *a*. Portion of sterile frond; *b*. pinnule of same twice natural size; *c*. tip of fertile frond, with seeds above and reduced pinnules below; *d*, *e*. detached seeds, twice natural size. After White.

the leaves much compounded into lobed segments. As the fruiting stage approached, some of the outer parts of the fronds were reduced in size and finally instead of pinnules or segments the

seeds were produced. These seeds were little, flat rhombodial bodies about an eighth of an inch long (see *Figure* 29 *d*, *e*), and had slight wings or expansions on the sides. They were probably somewhat fleshy and had at least two seed-coats. They were easily separated from the little stalk on which they grew, and the wings may have been a device for their distribution by wind, as it is well known that flat, winged seeds always fly farther from the parent plant than round, plump seeds.

This wholly unexpected finding of seeds in the genus *Aneimites* casts suspicion on a number of other obviously related forms, such as the form genera *Eremopteris*, *Pseudopecopteris*, and *Triphyllopteris*, whose fructification is still entirely unrecognized. Of course their fruit may never be found, but it is the hope of such possible discoveries that gives fascination and interest to the study of fossil plants.

As we have now learned something of the appearance and habits of these ancient seed-ferns, we are in position to raise some questions as to their probable origin, their kinship, and possible descendants. As the foliage of the seed-ferns is so nearly like that of the undoubted true ferns that the two cannot be distinguished, it was natural and logical to suppose that they had been derived from the true ferns, especially as the two show certain other points of agreement, such as the internal structure of the stems, the pollen-sacs, etc., and such was the view that prevailed for some time. But we are confronted by the fact that there were seed-ferns in upper Devonian time (see p. 65) that were just as typically seed-bearing and apparently just as perfect and highly developed as they were during any later period of their existence. They lived side by side with the true ferns, and beyond the resemblance in foliage and the one or two minor points just mentioned they were perfectly distinct, and they remained so. It is therefore considered impossible that the seed-ferns could have been derived directly from the true ferns. Whence did they come? Apparently we must fall back to a more ancient, more remote, suppositious ancestor that gave rise to the two divergent lines. But thus far no certain trace of this ancestral plant has been found.

Sphenophyllum. There are some very pretty little plants frequently found as impressions in Carboniferous rocks that show

clusters or rosettes of little wedge-shaped leaves on a slender stem. These are known as *Spenophyllum*. (See *Figure* 30.) The stem, the size of a lead pencil or smaller, is jointed, and has ribs,

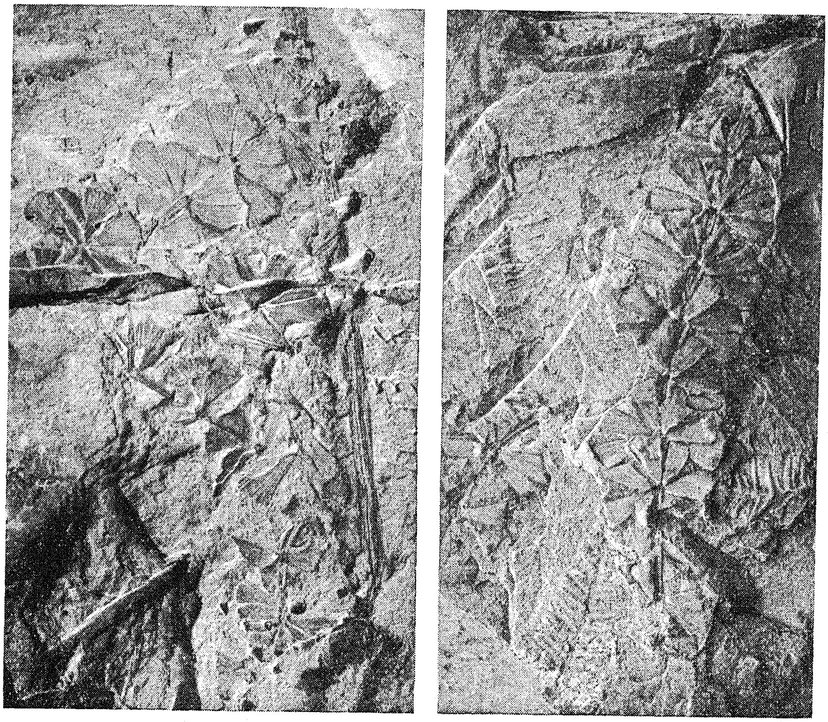


FIG. 30. Stems and leaves of *Sphenophyllum* from Carboniferous of Missouri. *a. Sphenophyllum emarginatum*; *b. Sphenophyllum cuneifolium*. Photographs from specimens in National Museum.

which, strangely enough, run the whole length of the stem, and do not alternate at the joints or nodes as do those of certain other plants with ribbed stems, such, for example, as the horsetails. In very young stems there is found in the center a solid triangle of wood which later may become more or less six-angled. The leaves grow in circles or whorls at the nodes, and are borne in sixes, or in a multiple of six, their number being probably determined by the shape of the woody element in the stem. The leaves in the best-known species are wedge-shaped, and attached to the stem by the

small end. The tips of the leaves may be entire, toothed, or cut up into narrow, almost hair-like divisions, as in certain living aquatic plants, which have the submerged leaves finely cut up and the higher floating leaves undivided. In fact, it was at one time thought that *Sphenophyllum* was such a water plant, but other species were found in which the finely divided leaves were in the upper part of the stem, and the lower ones were nearly or quite entire. It is now believed that it was a weak-stemmed plant that either climbed or depended on its neighbors for support.

The fruit of *Sphenophyllum* is very remarkable, being a long slender cone sometimes several inches in length and half an inch in diameter. The cones have a stout central axis and numerous whorls of overlapping scales with some fourteen to twenty scales in each whorl. Each scale bears two stalked spore cases on its upper face, these being filled with fairly large spiny spores, apparently all of one size. There are several other modifications of this kind of cone, but they need not be further considered here.

A number of years ago a single fragmentary cone from the coal measures of Cracau, Poland, was described under the name *Bowmanites*. It is probably the cone of another species of *Sphenophyllum*, but as no foliage leaves were found attached, it had to be given a different name. This cone is remarkable in that the little stalks bearing the spore cases are expanded at the top into a scale somewhat like the shield-shaped scales in the cone of the living horsetails, and further, each stalk bears two spore cases instead of one, as in the *Sphenophyllum* mentioned above.

There is also another kind of cone, called *Cheirostrobus*, that belongs here, although it is without foliage leaves, but it is so complicated that it cannot be considered further. It comes from the lower part of the Carboniferous rocks on the Firth of Forth, Scotland.

The sphenophyllums show so many remarkable features that they cannot be placed in any group, either fossil or living, and it has been necessary to put them in a group by themselves. This group is called the *Sphenophyllales*. They had their origin during late Devonian time, reached their greatest development in Carboniferous time, and passed forever from the stage before the end of Permian time. Although they did not leave what may be

called direct descendants, they were in the evolutionary line that led bewilderingly in several directions, and it seems that they must have descended from an ancient stock from which has come the lycopods and equisetums.

The Lepidodendrons. Although now small and comparatively insignificant and playing a relatively unimportant part among present-day plants, the little ground pine or crowfoot, which is so often gathered for decoration at Christmas time, is really of very ancient and distinguished lineage, for among its relatives were some of the largest and most splendid trees that lived in Carboniferous time. These trees are known as lepidodendrons, or scale trees. It we were to multiply the little ground pine a hundredfold it would then approximate in size to some of these scale trees, some of which were at least four feet in diameter

FIG. 31. Composite restorations of Carboniferous trees. ***Lepidodendron*** **in right foreground;** *Sigillaria,* left foreground; *Cordaites* and tree fern in background; *Calamites* in outer circle. From Chamberlin and Salisbury's *Geology,* Vol. II, Henry Holt & Co.

and a hundred feet or more in height. There is a splendid trunk of one of these trees on exhibition in the United States National Museum at Washington, which stands from floor to ceiling of the lofty exhibition hall—some thirty feet. It was pressed flat and is four feet across, and as it shows little or no decrease in size from bottom to top, it is estimated to have been about a hundred feet high when living. Some years ago the trunk of a giant *Lepidodendron* found in an English coal mine measured 114 feet up to its first branches, and the crown of branches extended for at least twenty feet above this, so that its height when living was over 135 feet. (See *Figures* 31 and 34.)

Lepidodendron had huge underground parts that look like roots, as may be seen in *Figure* 32, which is a photograph of a specimen in the United States National Museum. These underground parts are peculiar, however, for while they seem to be roots, their structure is not that of a root, nor does it agree with the stem, for it has no leaves nor traces of leaves, and its exact nature is not known. These underground parts are dichotomous—that is to say, they divide or branch into two equal parts, and each of these into two, and so on to the smaller divisions. This is why there appear to be four nearly equal parts, for the trunk divided at the base into two, and these again almost immediately into two others. These underground parts are marked quite regularly with circular scars, showing where "rootlets" emerged. These root-like parts are known as *Stigmaria*, and they are among the commonest fossils found in the coal measures. All lepidodendrons have these *Stigmaria* "roots," and curiously enough the same organ is found in *Sigillaria*, a group closely allied to *Lepidodendron*—in fact it is impossible to separate these trees by their "roots."

The trunk in *Lepidodendron* did not branch until near its top, and the branching, like that of the underground part, was strictly dichotomous, though, as the two branches of a fork did not always develop equally, the smaller branches may appear to be arranged along the side of a larger one. The branches are thickly clothed with small, more or less awl-shaped leaves set in a close spiral. The leaves are roughly four-sided at the base and run to a sharp point. Although the leaves in some species are six or seven inches long, they are seemingly small for the size of the tree. The

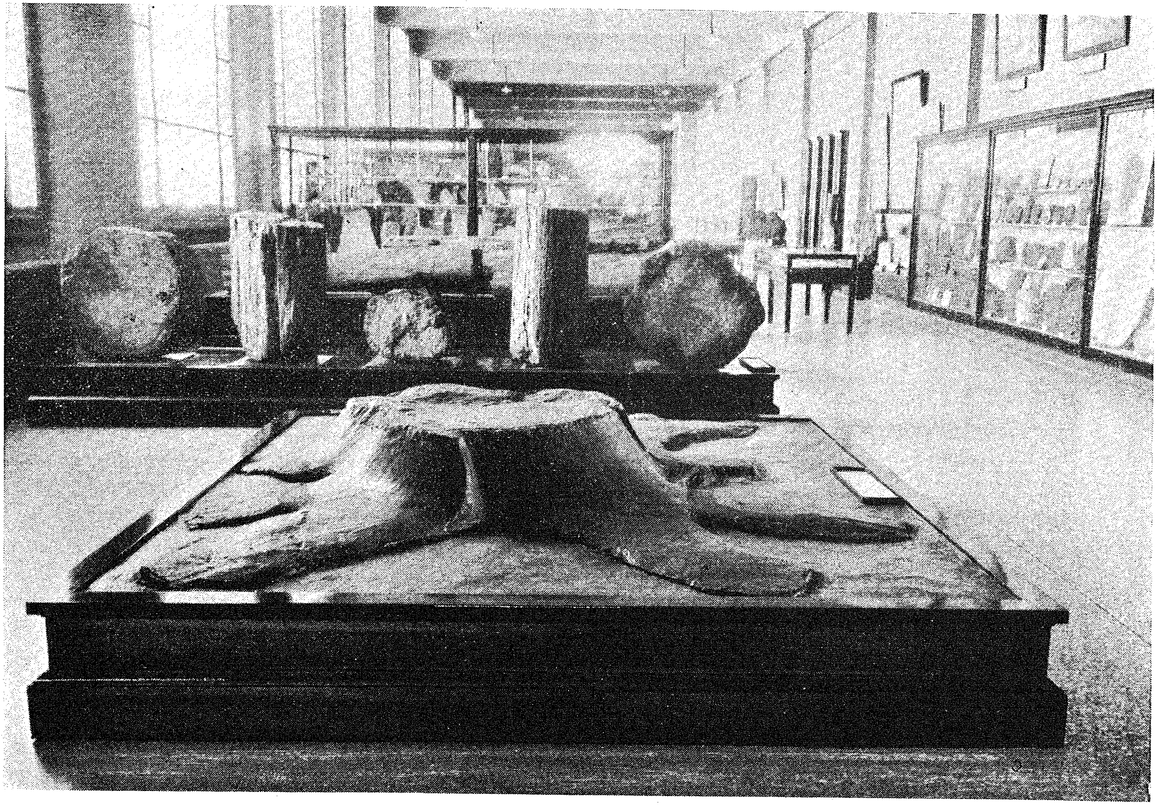
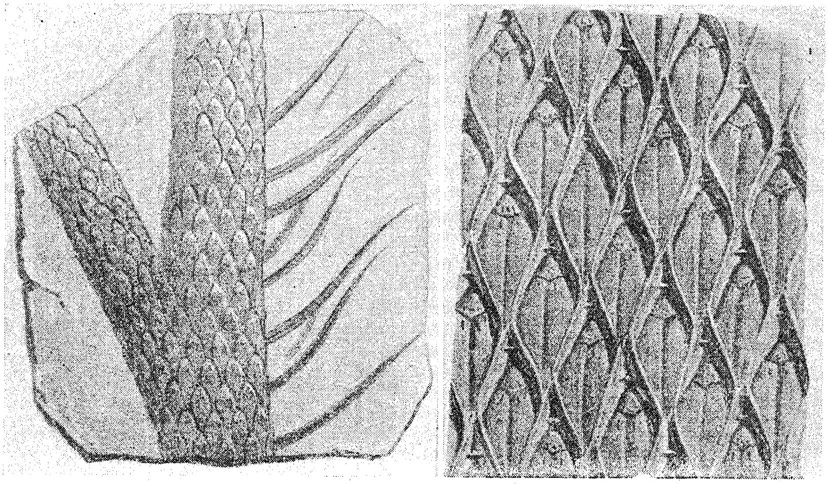


FIG. 32. Trunk of *Stigmaria* in foreground. Preserved in the Fossil Plant Hall, National Museum.

leaves apparently remained for a long time attached to the stem, but when they had fallen they left scars, or the so-called leaf-cushions, which are disposed in close, oblique rows around the stem. There are several small scars in the upper part of each cushion, which represents the points at which the bundles of vessels passed from the wood of the branch into the leaf. It is largely on the size and shape of the cushions and their scars that the hundred or more species of *Lepidodendron* are based. (See *Figure* 33.)



a *b*

FIG. 33. Leaf scars and their arrangement in *Lepidodendron*. *a*. Branching stem and leaves of *Lepidodendron sternbergii*. *b*. *Lepidodendron aculeatum*. After Schimper.

The trunk of *Lepidodendron* is of course distinctly woody, and there are two ways in which the woody elements are arranged. In one kind there is a distinct pith surrounded by a cylinder of wood, and in the other the wood is solid and without a pith. The first wood cells near the center have a spiral or ladder-shaped thickening, but outside this is what is called secondary wood—that is, wood with interspersed rays of thin-walled cells, connecting pith and bark.

The cones in *Lepidodendron* (often called *Lepidostrobus*) were borne on the tips of slender branches, and in some species at least were very large, specimens having been found that were twenty inches long and two inches in diameter. Roughly speaking

these cones resemble the little cones of the ground pine (*Lycopodium*). They have a strong axis about which are arranged whorls of slender bracts, or sporophylls as they are called, which bore the spore cases on the upper face or axil. In some species the spores appear to be all of one kind (homosporous), while in others there were two kinds, large ones called megaspores, in the lower part of the cone, and smaller ones (microspores) in the upper part. The cones apparently were loosened from the branches when they were mature, and the further processes of fertilization took place on the ground or in the water of the swamps in which or along which these trees grew. The cones must have been produced in great abundance to account for the numbers of spore cases and spores which are believed to have entered so largely into the formation of beds of coal, some of which are made up almost entirely of these minute bodies.

The Sigillarias. Associated with the lepidodendrons were other trees, also of very large size, known as *Sigillaria*, a name derived from the Latin word sigillum, which means a seal, in allusion to the deep scars left on the stems by the fall of the leaves. They must have been strange, not to say grotesque, in appearance, roughly suggesting certain huge tree cactuses of the western deserts. Thus a trunk of a species of *Sigillaria* found near Saarbrücken, in Germany, was six feet in diameter at the base and a foot at the top, and was only eighteen feet high. It was unbranched and must have looked more like a huge barrel than a full-fledged tree. Other species, however, were tall and slender, some indeed reaching a height of fully a hundred feet, and only two or three feet in diameter. Few of them were branched. For instance, one found in a coal mine in France was nearly a hundred feet long, was unbranched, and had the upper two feet of its trunk thickly covered with erect, sword-shaped leaves nearly three feet in length. Other species had much smaller leaves, which were not unlike those of *Lepidodendron*—in fact it is sometimes difficult to distinguish between them.

The leaves in *Sigillaria* evidently remained attached to the trunk for a considerable time, at least several years, but when they finally fell they left six-sided scars that have rounded angles—scars essentially like those of *Lepidodendron*, except that instead of being arranged in oblique rows, they are for the most part

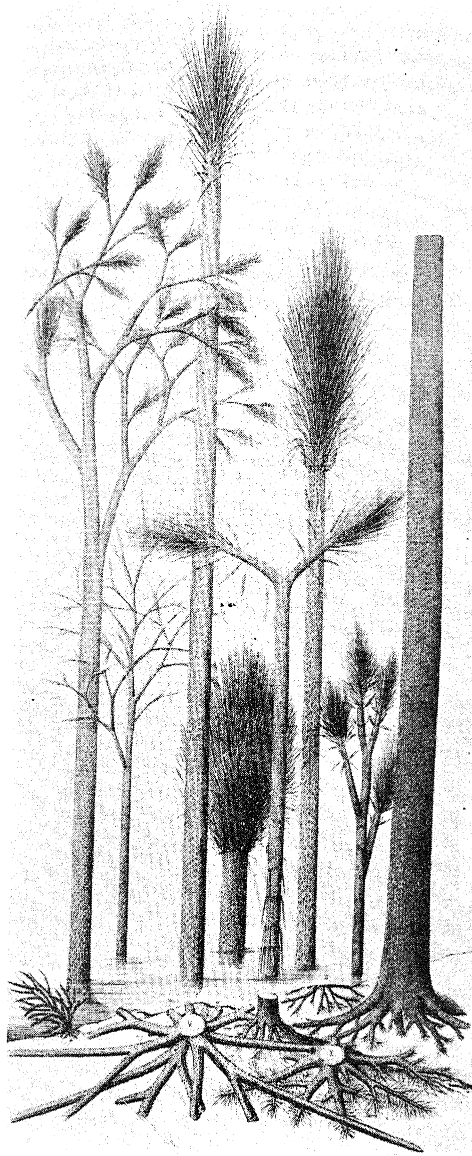


FIG. 34. Restoration of Carboniferous trees. Two on left side are *Lepidodendrons*; all others are different types of *Sigillaria*; types of *Stigmaria* in foreground. After Grand'Eury.

in distinctly vertical rows, as may be seen in *Figure* 34. In some trunks of *Sigillaria* the rows of scars are close together, with those in neighboring rows alternating, while in others the vertical rows are more or less separated by grooves. There is a good deal of variation in the scars and their accompanying grooves or ridges, and sometimes two quite different arrangements may be found in the same trunk. The bark or outer shell is in three layers, as shown in *Figure* 35. The surface in the upper right hand part shows

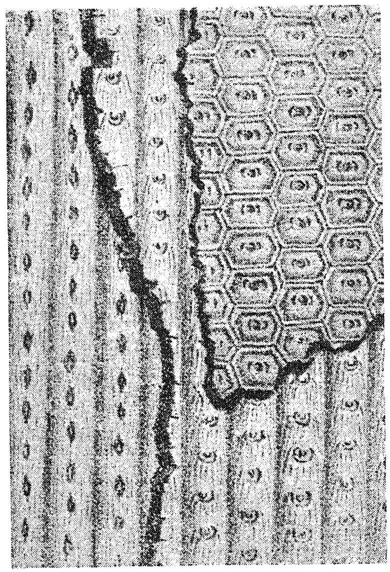


FIG. 35. Bark from trunk of *Sigillaria* showing the three layers. *a.* Outer surface with leaf scars; *b*, *c.* second and third layers, each with a different marking. After Schimper.

the characteristic scars of *Sigillaria*. When this layer is removed, as it often was by decay or otherwise, it discloses a quite different set of markings, and when this second layer was removed still another series of more nearly oblong scars was brought to view. Each of these were given a different name before it was discovered that they all belonged, or at least might belong, to a single *Sigillaria* trunk. An exceptionally well preserved trunk of *Sigillaria* from Kentucky, a portion of which is seen in *Figure* 36, shows the large leaf scars and the wrinkled bark between the scars.

The huge stigmarian underground parts of *Sigallaria* were mentioned under *Lepidodendron* (see *Figure* 32), for it is practically impossible to tell by which they were produced. They are often found erect and undisturbed in beds of clay beneath the coal beds, showing that they grew in those places, and that their trunks, leaves, and cones entered into the formation of the coal.

The cones of *Sigillaria* resemble those of *Lepidodendron*, but

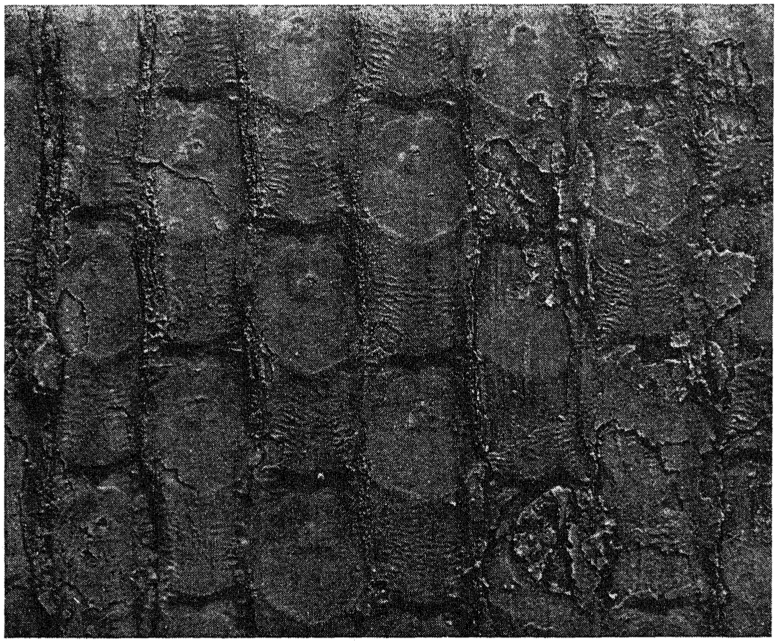


FIG. 36. Segment of exceptionally well preserved trunk of *Sigillaria mammilaris*, from Alabama, showing large leaf scars and wrinkled bark. Slightly enlarged. Photograph from Charles Butts.

instead of being borne at the tips of the slender branches, they were borne in a close whorl or circle around the stems, or sometimes in vertical rows. They fell off at maturity, leaving peculiar oblong scars. In some species the cones were large, reaching a length of twelve inches and a diameter of one or two inches. It is thought probable that the cones, or some of them at least, produced spores of two sizes, though only one size has been found. The spores were evidently produced in great abundance and contributed largely to the formation of coal.

There are a number of other forms more or less closely allied to either *Lepidodendron* or *Sigillaria*, but as they are not yet very well known they must be passed over. There is, however, one known as *Bothrodendron*, which had deep scars, two inches across, that at one time were thought to represent the fall of cones, but that are now believed to have been caused by the fall of a branch, a sort of self-pruning such as that seen in some living trees, the poplars, for example.

The Cordaites. In *Figure* 37 we have a restoration of a tree that at first glance may suggest some of the so-called tree yuccas that are such a conspicuous feature in the drier parts of our southwestern states; in fact when the leaves of this tree were first found they were thought to belong to the *Yucca* and thus to indicate the presence of the great group of monocotyledons in the Carboniferous period, but this idea was abandoned years ago. These trees are known as *Cordaites*, and they formed a very conspicuous element in the plant life of their time. For instance, certain important beds of coal appear to be made up almost entirely of the leaves of *Cordaites*. They had their origin late in the Devonian period and became exceedingly abundant and widespread in Carboniferous time, but, like so many of their associates, they had almost entirely disappeared by the close of the Permian, though some lingered on until perhaps near the end of the Triassic. Although they died out so many millions of years ago, their life history, from root to seed, is more completely known than that of many groups of plants that are living today.

The *Cordaites* were tall, slender trees, with the trunk sometimes two feet in diameter, though usually less, and from thirty to ninety or a hundred feet in height. They had a rather poorly developed root system, and did not branch until near the summit of the tall trunk. The branches were of various sizes and were thickly clothed with leaves, producing a splendid crown of foliage. The leaves were arranged spirally on the branches, and knowledge concerning them is so complete that the leaf arrangement—the phyllotaxy, as it is called—has been fully worked out. It is represented by the fraction 5/13, which means that, starting with any leaf, the spiral passes five times around the branch before coming to a leaf—the thirteenth—that stands directly over the first. There was considerable difference in the size and shape

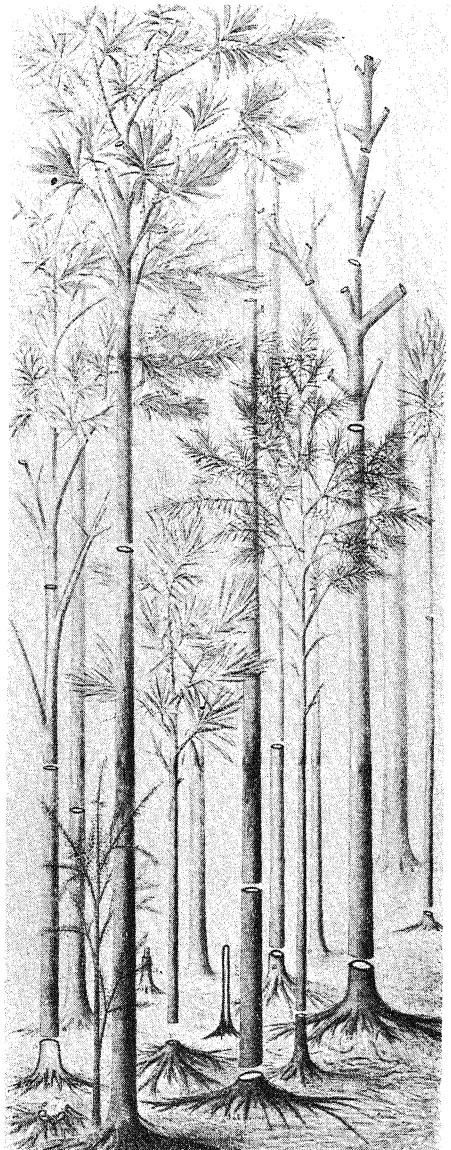


FIG. 37. Restoration of several types of *Cordaites*, ancient Paleozoic conifers. After Grand'Eury.

of the leaves in the several groups into which *Cordaites* has been divided. Thus in the several kinds shown in the restoration (*Figure* 37), the leaves range from narrow strap-shaped, and sharp-pointed, and three feet in length, to those with leaves that were spatulate, with very blunt ends, and were fifteen inches wide. In still another group they were almost grass-like, being some two feet long and less than half an inch wide. In all the species the veins in the leaves are parallel, and, except perhaps in forms having the narrowest leaves, they are freely forked. It was in these long narrow leaves with the close parallel veins that the resemblance to monocotyledons is so strong and at first led to their being referred to this group.

The internal structure of the trunk in *Cordaites* presents many interesting features. First, there is in the center of the trunk a very large pith, which in some species reached a diameter of nearly four inches. This pith, which is made up of small, thin-walled cells, was torn across at regular intervals, probably as the result of the growth of the trunk in length, so as to produce little disc-shaped open spaces, which were separated by a few layers of pith cells. Casts of the pith cavity show constrictions that correspond to the layers of cells between the open spaces, and that produce a body resembling a pile of coins. Fossils of this kind, such as the one shown in *Figure* 7, were long known under the name of *Artisia*, but little was learned of their nature until, fortunately, one was found in place in a trunk that showed the wood of *Cordaites*, when the whole matter was explained. Somewhat similar ruptures of the pith, though on a smaller scale, are seen in certain living trees, such for instance as in the English walnut (*Juglans*).

The trunk in *Cordaites* outside the pith is made up of long, thick-walled cells. The cells nearest the pith have spiral thickenings on the inner walls of the cells, then a series of cells having ladder-like thickenings, and finally the bulk of the trunk, which is composed of wood cells (tracheids) with two or three rows of peculiar, mostly six-sided markings, which entirely cover the wall. The feature last noted is seen also in the living *Araucaria*, the so-called Norfolk Island pine, and on this account the wood of *Cordaites* has often been called *Araucarioxylon*, or, better, *Dadoxylon*. There is undoubtedly a degree of kinship between the *Cordaites* and the living araucarias, though apparently not in

direct line. Extensions of the pith toward the outer margin or bark, called medullary rays, pass between the wood cells.

The wood of *Cordaites* shows no or but feebly developed growth rings—annual rings, as they are often but more or less erroneously called—indicating that when they were living there were no strongly contrasting seasons such as we now have, especially in temperate and cool climates.

Fructifications that are now known to belong to *Cordaites* were known and described long before it was recognized that they were borne by these trees. From the fortunate discovery of silicified material in France and elsewhere, which permitted the cutting of thin slices and their study under the compound microscope, the fructifications of certain types of *Cordaites* are very well known, but as their description would require extremely technical language, this may be passed over, merely stating that the "flowers" occur in catkins which arise from the stems just above the leaves but not in their axils. The sexes are in separate catkins, the male bearing pollen sacs filled with oblong pollen grains, and the female consisting of a seed at the base of the bracts or modified leaves.

Seeds thought to belong to *Cordaites* and its relatives are very common objects in many Carboniferous rocks, though only a comparatively few of them have been found actually connected with leaf-bearing parts of these trees. They are more or less heart-shaped at the base and had an outer fleshy coat, which, of course, has now disappeared, and a hard, shelly or woody inner coat. They were mostly flattened and were often ribbed and ridged. A great many seeds have been described under various names that are presumed with a reasonable degree of certainty to have belonged to the *Cordaites*, though it should not be overlooked that it is not easy to distinguish between these and seeds of the seed-ferns.

From this brief account of these interesting trees, it is evident that *Cordaites* had an undoubted kinship with a number of other groups, such as the seed-ferns, the cycads, the ginkgoes, and certain modern conifers. This would indicate that they all had a common ancestor somewhere in the remote past. What caused their disappearance we of course do not know, for it would seem that with their tall, woody trunks and their having acquired the seed-bearing habit they were especially well fitted to compete

for "a place in the sun" of post-Carboniferous time; but they must have had somewhere a fatal weakness that terminated their career.

The Calamites. In the olden days the housewives gathered certain slender pipestem-like or rush-like plants that were harsh and rough to the touch, with which to scour their pots and pans, and hence these plants came to be known as scouring rushes. From their fancied resemblance to a horse's tail, they are better and more widely known as horsetails, and this word, translated into Latin, becomes *Equisetum*, the scientific name by which botanists know them. They are for the most part small plants from a few inches to three or four feet in height, though there is a single species in South America that has stems an inch in diameter and thirty or forty feet tall. They are perennial plants with underground stems, which send up shoots each year. These shoots may be of two kinds: in some species the ordinary green shoot bears the reproduction spike at the top; in others there is a special reproduction shoot, usually appearing in spring, and often without green coloring matter, which withers and disappears as soon as reproduction has been accomplished. The ordinary shoots are often much branched. The living equisetums, of which there are some twenty-five species, which are widely distributed in temperate and Arctic regions, have hollow, jointed and ribbed stems and leaves reduced to toothed sheaths at the joints. The epidermis is impregnated with silica; whence comes their roughness to the touch.

So much for the living equisetums, which have here been rather fully described as having a bearing on the evolutionary history, for, be it known, they have followed a very long pathway which takes them back among the earliest land plants known, perhaps into Devonian time, and the interesting point is that they have come down from ancient to modern time with relatively little essential change or modification. Although they had their greatest development during Carboniferous time, when some of them had trunks two or three feet in diameter and fully a hundred feet high, their obvious kinship with the little modern equisetums is easily recognizable.

The Paleozoic representatives of the group are known as *Calamites* (see *Figure* 31), and they are among the commonest fossils

found in Carboniferous rocks, where they occur mainly as sandstone casts of the interior of the hollow stems, but they are also found as impressions of stems and various organs, and a few have been found so perfectly preserved that the internal structure has been worked out very completely. They had underground, or at least prostrate stems, from which the upright trunks rose. They evidently grew in very wet, swampy places and are supposed to have formed dense jungles somewhat like the so-called canebrakes of the South. Their abundance is inferred from the fact that in some places beds of coal, called paper coal, are made up almost entirely of their cuticles.

The *Calamites* bore branches in whorls at the nodes or at special branch-bearing nodes, which were in some forms widely separated. The leaves are also in whorls or circles at the nodes and are mostly of two kinds. In one genus, known as *Asterophyllites*, the leaves are very narrow, almost thread-like, and one-nerved, and are not united at their bases, while in the other, called *Annularia*, the leaves are much broader, often of unequal lengths, and slightly united by their bases. The first kind are borne on very slender branches; those of the last on much thicker branches. The annularias are common and very pretty objects on the shales of the Carboniferous rocks. (See *Figure* 39.) It is necessary to keep the several different kinds apart and under different names because it is difficult, not to say impossible, to join them with certainty. That is, it is impossible to connect leaves preserved as impressions with sandstone casts of the interior of stems, and for the same reason it is necessary to give different names to the several types of cones and internal structures, some of which are known from impressions and some from silicified material, although it is very certain that they all belong to some kind of a calamite. This uncertainty is due to what is called the "imperfection of the geological record," and it may continue indefinitely, though with the increase in the number of students and the growth of collections, some or all of these uncertainties may be overcome.

The calamites bore cones that in some species were a foot long and an inch or more in diameter, though they were mostly much smaller. Each cone has a central axis and bears whorls of modified leaves or bracts, in the upper angles of which were the large spore cases. In some species the spores were all of one kind while

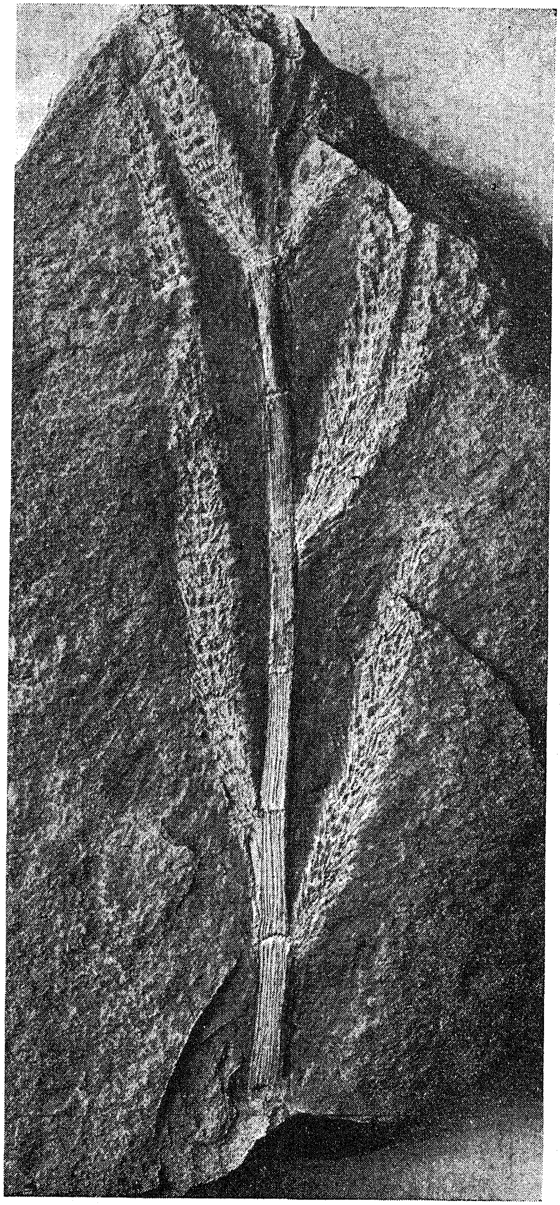


FIG. 38. *Calamostachys lanceolata*, a fertile shoot of *Calamites*. Photograph from specimen in National Museum.

in others they were of two kinds. The cones apparently fell off at maturity and the final processes of reproduction were completed on the ground or in the water in which they grew. (See *Figure* 38.)

Conifers. Before leaving the consideration of the Carboniferous floras a word may appropriately be added regarding the probable presence of the great group of conifers. From the fact that

FIG. 39. *Annularia stellata*, the foliage of a species of *Calamites*. Photograph from a specimen in National Museum.

the group became so firmly established and diversified in the succeeding Mesozoic era, the inference seems logical that it must have had its beginning in Carboniferous time, and this is probably true, though available facts on this point are not as conclusive as could be wished. The group of *Cordaites*, considered on previous pages, is undoubtedly gymnospermous, and may possibly be in line with certain modern conifers. It is the plexus from which, or through which, the maidenhair trees (*Ginkgo*), and the cycads had their origin, and the structure of the wood is certainly strongly suggestive of the modern araucarias, but it is doubted by many that this resemblance is a conclusive indication of kinship.

Probably the most distinctive of these supposed Paleozoic conifers is called *Walchia*. It is known mainly from foliage branches and branchlets, such as shown in *Figure* 40. There is a central axis or branch with numerous slender branchlets at right angles or slightly oblique arranged along its sides. These are densely clothed with small spirally arranged leaves, which are linear or short and ovate, more or less four-sided at the base, and usually spreading at the tips. Some specimens of *Walchia* branchlets have been found that bore cones, but they are so poorly preserved that little could be determined regarding the position of the seeds, and almost nothing is known concerning the structure of the wood. Specimens of petrified wood showing araucaria-like structures have been found in such close association with foliage branches of *Walchia* as to make it reasonably certain that they belong together, though the absolute proof is lacking.

The ordinary foliage shoots of *Walchia*, such as shown in the figure, are at once strongly suggestive of similar sized shoots of the living *Araucaria excelsa*, and this, taken in conjunction with the possibility that the wood above mentioned belongs with the foliage, points rather strongly to relationship with the living *Araucaria*, though perhaps not sufficiently close to warrant placing them in the same family. The size and general appearance of *Walchia* when living is not well known.

Walchia was abundant and widely distributed during upper Carboniferous and Permian time, with somewhat questionable evidence that it persisted into Triassic time. Upwards of forty nominal species have been described, but it is doubtful if more

than a fourth of this number are sufficiently distinct to merit recognition.

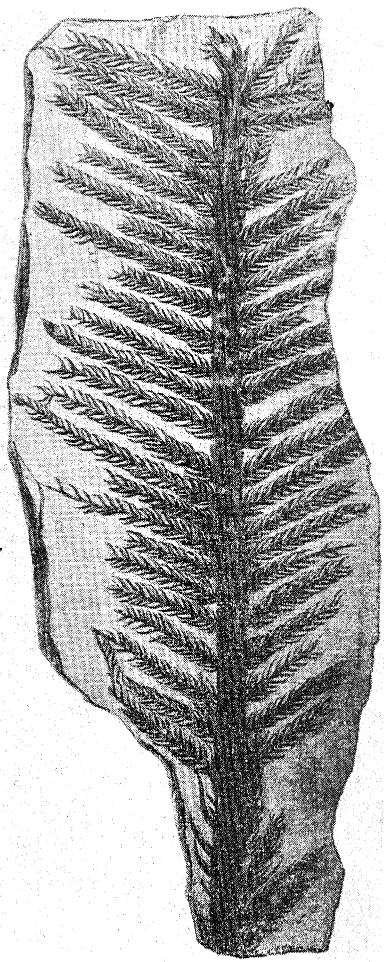


FIG. 40. Leafy branch of a Carboniferous conifer (*Walchia pinniformis*). One-half natural size. After Schimper.

About a dozen other genera of probable conifers have been described from Upper Carboniferous and Permian rocks. They are based on foliage shoots, impressions of stems, some of large size and peculiar markings, pieces of petrified wood, isolated cones,

etc., but none is sufficiently well known to permit a satisfactory interpretation of their systematic position or probable living descendants. They are, however, seemingly sufficient to indicate the presence of several apparently distinct types of conifers in late Paleozoic time.

The Glossopteris Flora. In Permian time, which is regarded as the last epoch of the long Paleozoic era, there was a very profound change in the character and distribution of the plants. As we have already seen, during Carboniferous time plants enjoyed a practically world-wide distribution, as many of the same forms have been found in rocks of this age at many places in the southern as well as in the northern hemisphere. This fact shows that the climatic conditions must have been uniform throughout much or all of the world, else the plants could not have spread so widely, and further, this climate must have been very mild, possibly even sub-tropical, with an apparent absence of frost, as shown by the practically universal absence of growth rings in the tree trunks, as well as by the soft, fleshy, luxuriant character of many of the plants, and in other ways. Then there suddenly came this remarkable change. In what is believed to have been early Permian time, there came about, from causes not yet fully explained, a period of severe glaciation, which was perhaps more intense than the so-called Pleistocene glaciation. The area covered by the Permo-Carboniferous ice age included parts of Australia, Tasmania, India, South Africa, and at least Brazil in South America. Much of this vast area, parts of which are now sunk beneath the sea, was then elevated, and, as Berry says: "From the combined evidence of the organisms, their distribution, and the continental character of the deposits, geologists have restored from the depths of the present seas a vast southern continent extending from Australia to India, and thence to Africa and South America, which is called Gondwana Land, and which existed throughout the Permian and the first half of the Mesozoic. It was very probably connected southward from both Australia and South America with the land mass in the south polar region known as Antarctica, and a restricted land bridge connected it across northwestern Africa with southwestern Europe."

The effect of this ice invasion was naturally very profound, and very disastrous to the previously widespread Carboniferous

flora, which was almost completely blotted out from the southern hemisphere, and although it continued with little change in the northern hemisphere, it was unable, except in one or two cases, ever to regain the lost ground. This Permian ice age was probably not very long as geologic time is reckoned, and there were several times during which milder climates prevailed for short periods, but in any event it was sufficiently long for a wholly new flora to be developed in the place of the former Carboniferous flora, and for it to spread widely over Gondwana Land. This is known as the *Glossopteris* or *Gangamopteris* flora, and is so called from its two most abundant and characteristic plants. Both were rather coarse fern-like plants with simple unlobed leaves (fronds) that were borne on creeping stems, which, from their fancied resemblance to a vertebral column, were long known independently as *Vertebraria.* (*Figure* 41 *c.*)

Glossopteris, of which about a dozen species are known, was often dimorphic—that is, it bore leaves of two sorts, the ordinary foliage leaves, which show no indication of producing fruit, and smaller so-called scale-fronds, or leaves on which were borne such fruiting organs as are known. The sterile leaves are usually long and narrow, though some are ovate or even spatulate in shape. They range in length from an inch or two to twenty inches or more. The nervation consists of a very strong midrib and a network of fine veins. The shape and nervation of two of the best-known species is shown in *Figure* 41. Several different types of fruit have been reported by a number of students, but they are all so doubtful that nothing has been settled. One of the latest types described consists of some minute bottle-shaped bodies found on a specimen from New South Wales. These bodies were attached to the surface of a scale-frond, and appear to be spore cases, but they are very peculiar in shape and are not known to contain spores. If they have been correctly interpreted as spore cases, the plants could not be referred to any known family of ferns, so the best that can be said is that they are fern-like plants. A well known species of *Glossopteris* was found by the Scott Antarctic Expedition within a few degrees of the South Pole.

Gangamopteris (*Figure* 42 *a*), of which some five or six nominal species are recognized, was a rather coarse, unattractive plant much like *Glossopteris* except that the leaves are without a

midrib. It is not known whether the leaves were dimorphic, and the fruit is unknown, hence it is impossible to place it. It was even more widely distributed than *Glossopteris*, though it evidently was never so abundant.

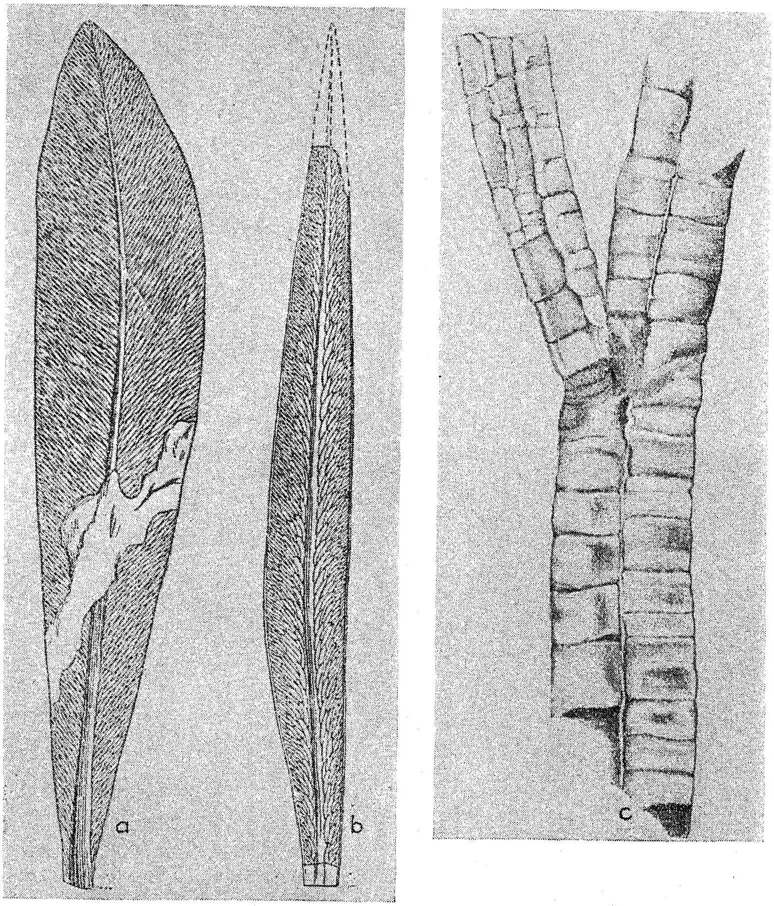


FIG. 41. Plants of the *Glossopteris* flora. *a. Glossopteris indica*; *b. Glossopteris angustifolia*; *c. Vertebraria*, the stem of *Glossopteris*. After Feistmantel.

Another rather remarkable member of the *Glossopteris* flora is known as *Neuropteridium* (*Figure* 42 *b*). This was a large pinnate "fern" with a very stout stalk (rachis) and numerous pinnules or segments arranged along its sides. Those in the lower

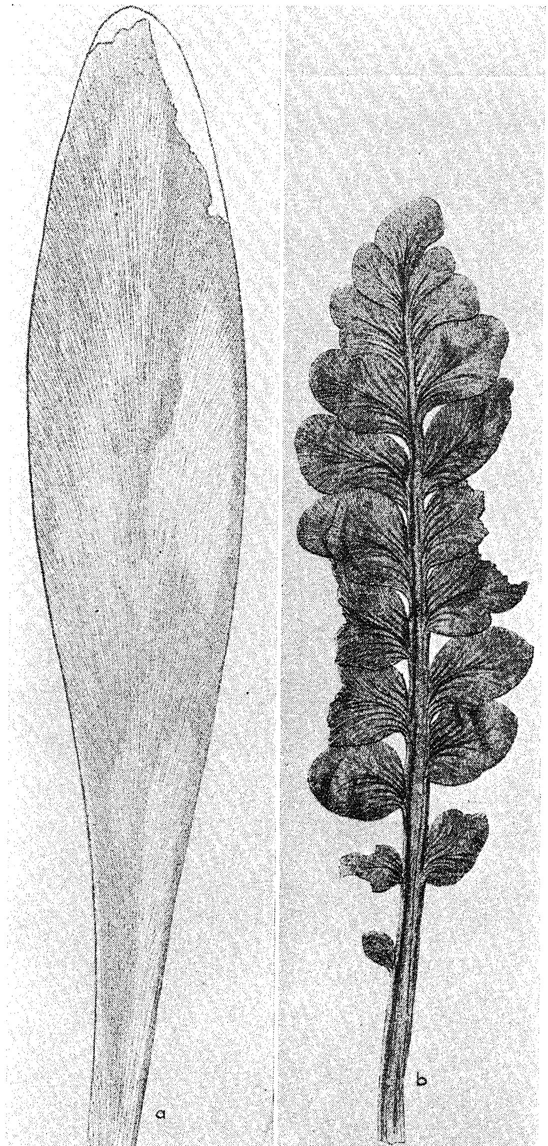


FIG. 42. Plants of the *Glossopteris* flora. *a. Gangamopteris major*; *b. Neuropteridium validum*. About one-half natural size. After Feistmantel.

part are entire and more or less semicircular in shape, passing in the middle and upper portions into large, often lobed segments. The veins are spreading, curving toward the edge of the segments, and are many times forked. No fruits have been found, and so it cannot be placed with certainty, some evidence suggesting that it may be a gymnosperm rather than a real fern. *Neuropteridium* continued on into Triassic time.

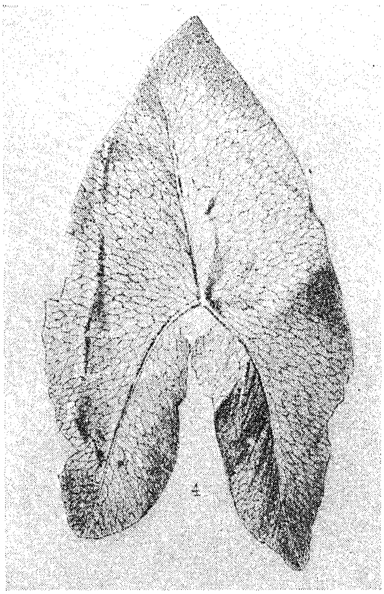


FIG. 43. Plants of the *Glossopteris* flora. Leaf of a supposed fern (*Belemnopteris*) from the Permian of India. After Feistmantel.

There are several other ferns or fern-like plants but there is space for mention of only one, shown in *Figure* 43, called *Belemnopteris*. It had a simple arrow-shaped leaf with three strong ribs passing to the three lobes, and a fine regular network of veins. It must have been a very striking plant, but not much is known of its habit of growth, and its fruit has not been found.

We have already seen how the bulk of the old Carboniferous flora was blotted out of the southern hemisphere by the cold, the exceptions being three or four species of *Lepidodendron* and a single *Sigillaria*, which are found with the *Glossopteris* flora in

Brazil and in South Africa, but are unknown in India and Australia. Whether these had been able to adapt themselves to the cooler climate, or had persisted in northern Africa and northern South America and returned only when conditions for their existence were more favorable, is not certainly known.

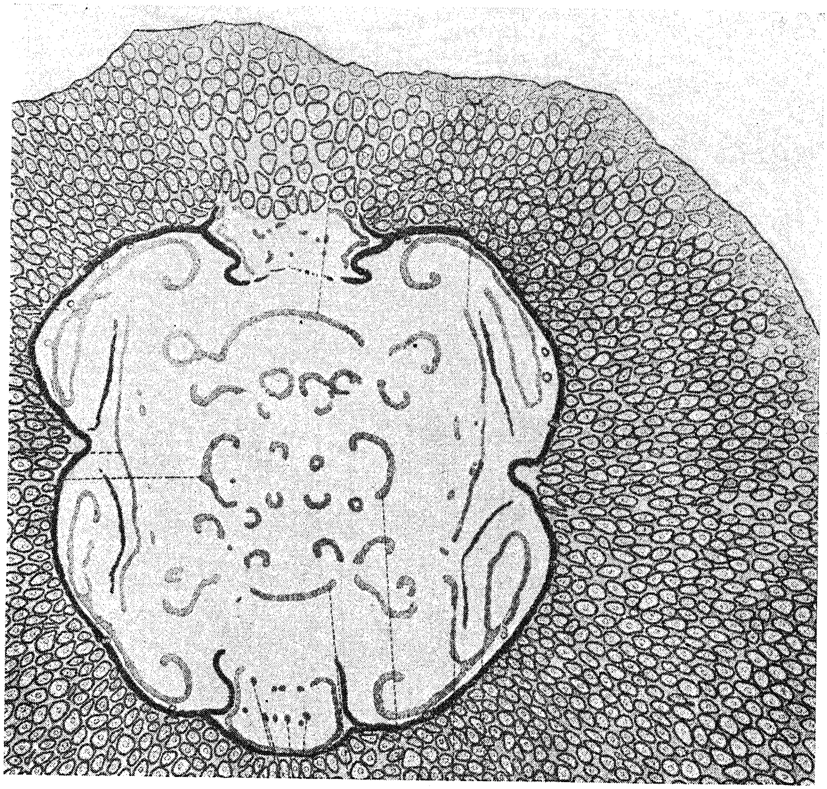


FIG. 44. Section of the trunk of a tree fern (*Psaronius braziliensis*) from the supposed Permian rocks of Brazil. After Zeiller.

Besides the plants of tree-like size just mentioned there were several other trees that were members of the *Glossopteris* flora, among them a tree-fern (*Psaronius*) that lived in Brazil. (*Figure* 44.) It had huge trunks two feet in diameter and probably sixty feet high, but the leaves and fruits it bore are not certainly known. True *Cordaites* (see page 93) have not been found in this flora, but

there was a form, known as *Noeggerathiopsis*, that was evidently closely related to it. This plant had large coarse-looking leaves that suggest in size and shape the leaves of *Gangamopteris*, already described. The leaves were without a midrib, and had numerous veins that forked repeatedly yet did not join to make a network, as in the latter form. It is found in India, New South Wales, Tasmania, South Africa and probably in Argentina. What may well have been the trunks of this form are represented by several silicified trunks called *Dadoxylon*, which have the peculiar six-sided pits on the wood cells, as already mentioned.

Chapter VIII

THE TRIASSIC AND ITS PLANT LIFE

WITH the close of Permian time the vast Paleozoic era came to an end, and we enter what is called the Mesozoic era, which means the time of *Middle life*, although as a matter of fact the Paleozoic was undoubtedly many times longer than the Mesozoic. It was formerly supposed, and indeed the view is still held by many, that the change in the forms of life between the Paleozoic and the Mesozoic was very abrupt, but as the facts are more closely studied the world over it is found that the change was really rather gradual. Most of the great groups of plants and animals "carried on" for a time, though often reduced in size and relative abundance, and came more and more to foreshadow their descendants of the present day. The Mesozoic era is divided in ascending order into three periods: the Triassic, the Jurassic, and the Cretaceous.

The Triassic system of rocks is so named because in North Germany, where it was first thoroughly studied, it consists of three distinct parts. Of these, the middle portion was deposited in salt water, thus indicating that the ocean was then spread over that part of North Germany. The lower and upper parts were formed almost entirely as land deposits which are made up largely of very coarse-grained rocks that are not well fitted to preserve plants. Another fact that comes in at this point may explain in part why so few Triassic plants are preserved. In many parts of the world, notably in the western interior of North America, the earlier Triassic rocks are red in color, and this is thought to indicate absence of moisture and hence a very dry climate, or perhaps desert conditions. There are also Triassic deposits of salt, as well as of sandstone, that seems to have been built up by wind-blown sand, but whether or not these deposits really indicate desert conditions, it is a fact that very few plants are found in the early Triassic rocks, and most of these are poorly preserved.

There is, however, one notable exception—the famous fossil forests of Arizona—which are of early Triassic age. (*Figures*

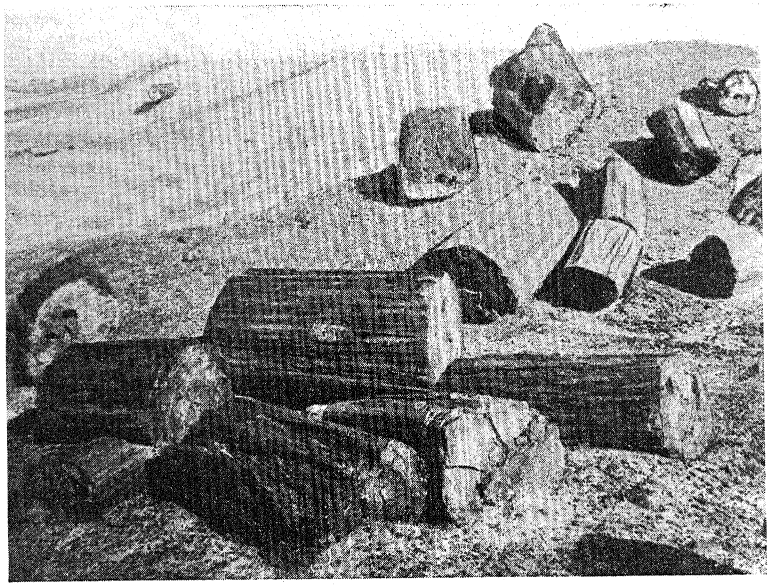


FIG. 45. Segments of fossil logs in the Fossil Forest, Chalcedony Park, Arizona.

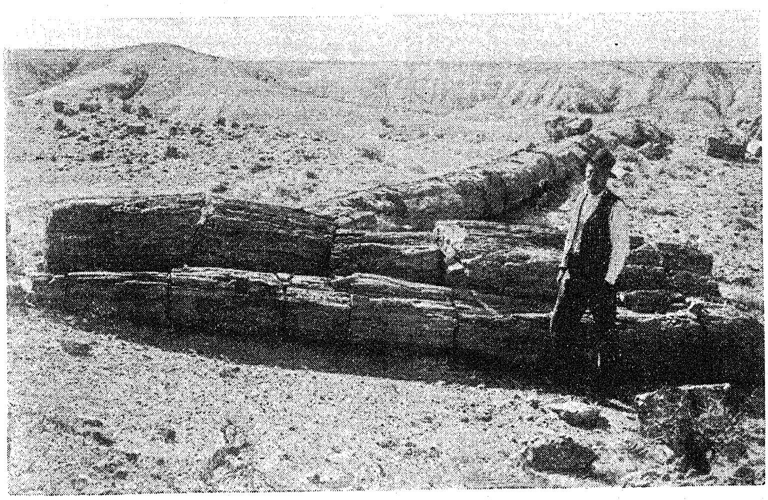


FIG. 46. Fossil trees in the Fossil Forest, Chalcedony Park, Arizona.

45 and 46.) Over hundreds of square miles in central Arizona, there are scattered pieces of fossil wood, and occasional trunks, but in an area of about forty square miles in southern Apache County, that has been set aside as the Petrified Forest National Monument, there are three veritable fossil forests. As one views these fossil forests from a little distance with their hundreds, even thousands, of fossil logs, it is hard to realize that they are really turned to stone. The appearance is not unlike a "log drive" that has been stranded by the receding waters and left until the bark had disappeared and many of the trunks fallen into partial decay. Trunks of all sizes and lengths are now mingled and scattered about in the wildest confusion, and the surface of the ground is carpeted with fragments of wood that have been splintered and broken from them. The average diameter of the logs is perhaps three or four feet and the length may range from sixty or eighty to a hundred feet. One log was over seven feet in diameter and 125 feet long.

One huge trunk forms a natural bridge, perhaps the only one of its kind in the world. (*Figure* 47.) This trunk, which is four feet in diameter at the base and eighteen inches at the tip and is 111 feet long, now, like the stringer of a man-made bridge, completely spans a little ravine some thirty feet across and more than twenty feet deep. On the bottom and along the sides of the little ravine over which one may cross on the "fossil bridge" are seen scrubby cedars and straggling cottonwoods, mute witnesses of the change since the great forests, now fossil, were living. Much of the wood, which is now agatized or changed to chalcedony, shows the most varied and beautiful coloring—the richest reds, yellows, and purples, all heightened by the polish made by the wind-blown sand which makes each piece seemingly more beautiful than the first. It almost finds a place among the gems or precious stones, and before the forests were set aside as a National park, much of the wood was taken away and cut into various objects of art.

None of the trees now stands upright in the position in which it grew, nor has any been found that retained its branches, though petrified limbs and small twigs are found. They were evidently brought to their present place by running water, perhaps for hundreds of miles. They were fossilized by percolating underground waters holding silica in solution, and are now exposed by

the erosion of the soft sandstone and clay in which they were entombed.

The trees in the Arizona forests were all coniferous, and they lived long before the precursors of our present-day trees had appeared. At least two kinds of trees are represented, the most

FIG. 47. A fossil log foot bridge in the Fossil Forest, Chalcedony Park, Arizona.

abundant one to which most of the wood belongs, is known as *Araucarioxylon*, which means wood of the *Araucaria*, a pine-like tree that does not now live in the northern hemisphere. The other kind, called *Woodworthia*, is also related to the araucarias but shows a number of different characters.

In the mountains of New Mexico, not far from the Arizona fossil forests, is another place where Triassic plants have been found. One of the most interesting plants found here is one that seemingly cannot be distinguished from a true *Equisetum* or horsetail. It had stems or trunks four or five inches in diameter, and of unknown height, but as its stems are preserved only as sandstone casts, very few of the details can be made out. The largest living horsetail is thirty feet or more in height and only an inch in diameter. The New Mexican specimens are thus seen

to be intermediate in size between the giant calamites of the Paleozoic and the modern species, and it is more than likely, if we knew the whole story, we might find that they were neither calamites nor true equisetums, but stood somewhere between them.

In the same beds with the equisetum stems were some fragments of fern leaves and some well-defined leaves of cycads, thus showing that these two groups of plants were "carrying on" to take their places among present-day plants.

Of course we do not expect to find remains of a land flora preserved in marine beds, but there were undoubtedly land areas all through Triassic time in some parts of the world, while other portions were covered by the sea. But important evolutionary changes were evidently going on, and by the time the upper portion of the Triassic was reached very striking changes from the Paleozoic floras had taken place. The lepidodendrons, sigillarias, calamites, *Cordaites*, and the wonderful group of seed-ferns, as such, had disappeared. From their dominant and commanding place in the ancient world, some had disappeared utterly, while others were henceforth to be known only by their small and more or less obscure descendants.

Conditions of moisture and climate having been more favorable in upper Triassic time, we have been able to recover a land flora of nearly four hundred species, which serves to give a fair exposition of the plant life of the time, though they are probably only a fraction of the plants that were actually living. Beds containing plants of this time are known from Mexico, North Carolina, Virginia and Pennsylvania, Europe, Asia, South Africa, and Australia. The Virginia plants are found in what is called the Richmond coal basin, a small area just west of the city of Richmond. There are about a dozen beds of coal, which altogether have a thickness of some thirty feet, showing that there was a long quiet swamp condition during which the plants grew and were converted into coal. Over forty different kinds of plants have been found in the clay shales above and below the coal beds in the Richmond Basin. They are for the most part ferns, and some of them were evidently of large size, probably like small tree-ferns in size and habit.

These ferns belong to two quite different groups, the one

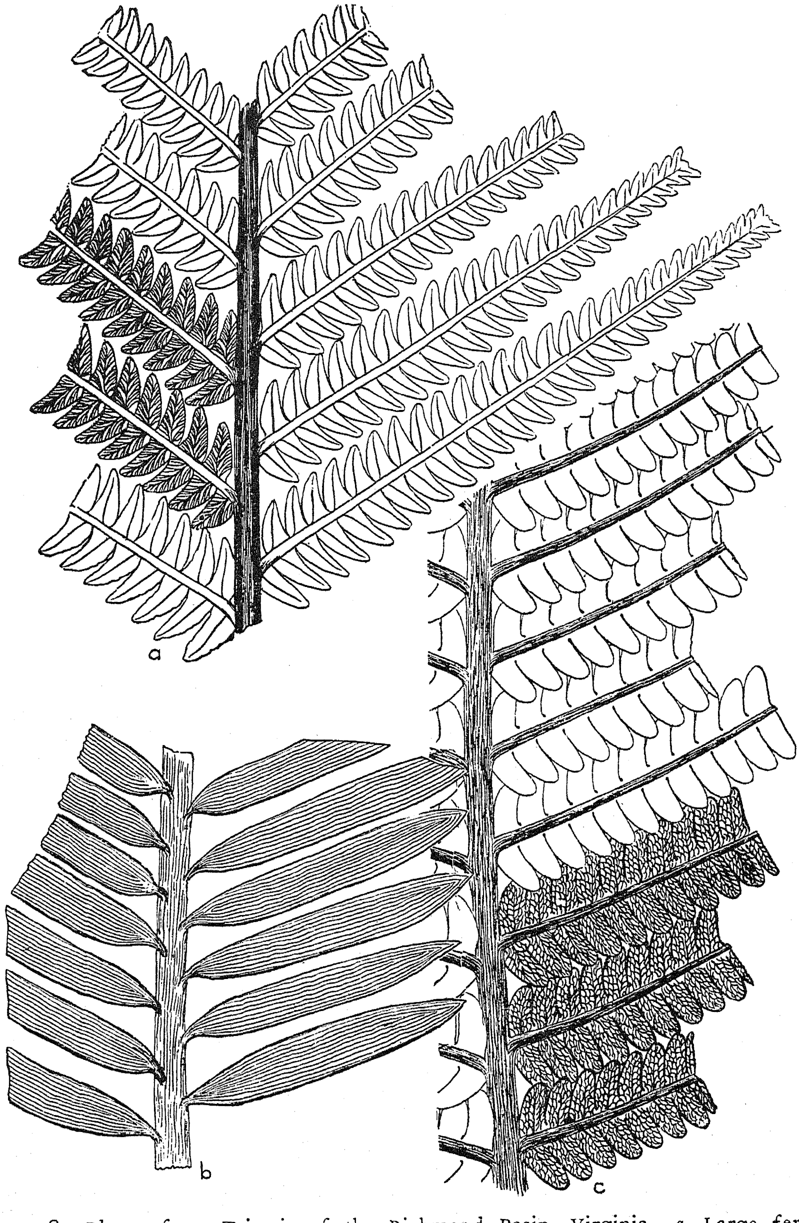


FIG. 48. Plants from Triassic of the Richmond Basin, Virginia. *a.* Large fern (*Acrostichites tenuifolius*); *b.* supposed cycad (*Podozamites emmonsi*); *c.* fern (*Lonchopteris virginiensis*). After Fontaine.

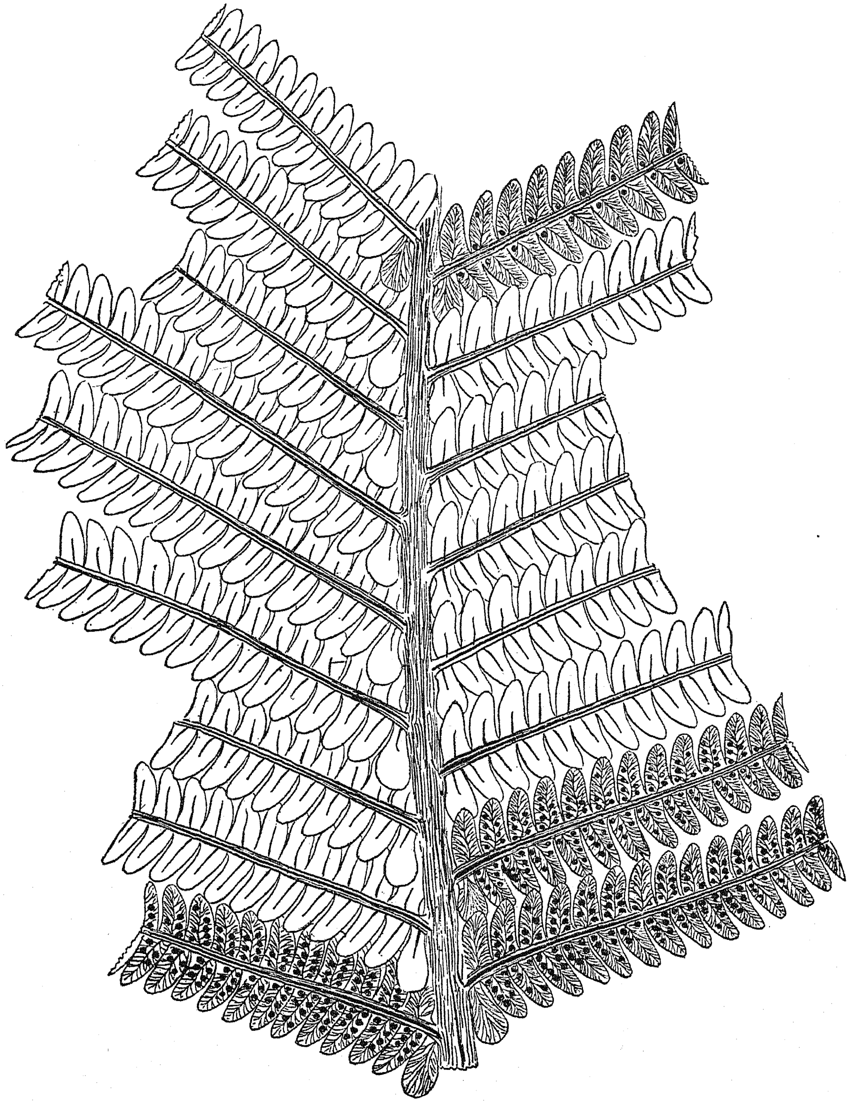


FIG. 49. Portion of the leaf of a large fern (*Mertensides bullatus*) from Triassic of the Richmond Basin, Virginia. After Fontaine.

showing undoubted kinship with those of the late Paleozoic, while the other group includes the forerunners of some five or six of the living families. One of the handsomest members of the first group, known as *Acrostichopteris*, is shown in *Figure* 48 *a*. This is only a part of a large leaf that must have been two or three feet long, and is cut into numerous small segments or leaflets (pinnules). Another almost as large and quite as handsome was *Lonchopteris*, a part of which is seen in *Figure* 48 *c*. Still another, called *Mertensides*, is seen in fruit in *Figure* 49. Of quite a different type but equally striking was *Macrotaeniopteris*, a restoration of which is seen in *Figure* 50. This had simple undivided leaves, often six inches wide and three or four feet long, growing from a crown, not unlike our cinnamon ferns (*Osmunda*). Altogether these ferns of the "old school" must have presented a very pleasing picture as they grew in such profusion in and about these great swamps. They probably were among the largest contributors to the forming coal beds.

The group which includes the ancestors of the modern ferns was not a very conspicuous element in the flora of the Richmond Basin, though there is one, known as *Clathropteris*, that is deserving of special mention. This fern, shown in restoration in *Figure* 51, had large palmate fronds, nearly circular in general outline, deeply cut into from five to fifteen large lobes, some of which were a foot or more in length, and three or four inches in width. The margins of the lobes were strongly toothed. The midveins were very strong, and are provided with numerous parallel ribs ending in the marginal teeth. The area between the ribs is filled with a strong, mainly polygonal network of veins that strikingly suggest the nervation of the leaves of certain flowering plants (angiosperms); in fact fragments of *Clathropteris* fronds have not infrequently been mistaken for plants of this kind.

Clathropteris is closely related to a group of living ferns (*Dipteris*) which comprises five or six species of small ferns living in tropical India, China, Borneo, and the East.

One of the most interesting plants that lived in the Richmond Basin during Triassic time is called *Neocalamites*. It was in a way intermediate between the Paleozoic *Calamites* and the living horsetails (*Equisetum*), though, as we shall see presently, it was undoubtedly much nearer the former than the latter. It had

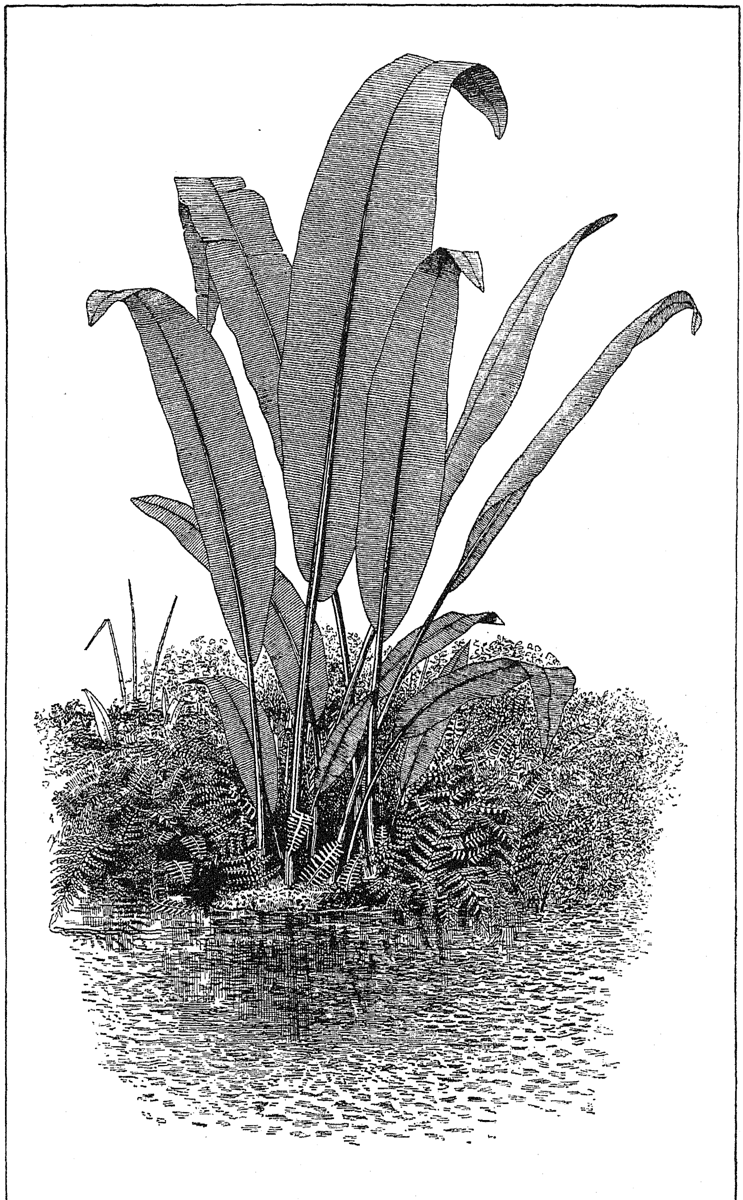


FIG. 50. Restoration of a large supposed fern (*Macrotaeniopteris magnifolia*) from the Triassic of Richmond Basin, Virginia. After Russell.

upright stems at least four or five inches in diameter and some fifteen or twenty feet long. The stems were divided into nodes

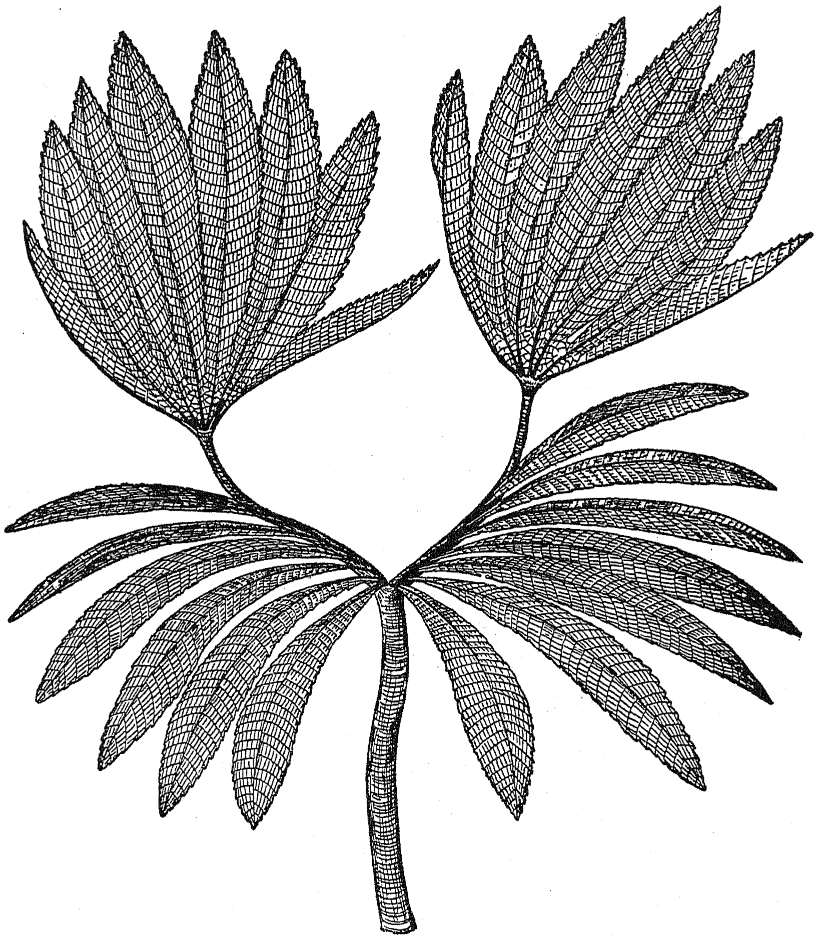


FIG. 51. Restoration of *Clathropteris*, a large fern from the Triassic of Virginia. About one-third natural size. After Berry.

or joints very much like the stems of our horsetails, and they were provided with numerous ribs or ridges, which, unlike those of *Equisetum*, did not end at the nodes. In the upper part of the stems there were whorls of graceful leafy branches. The leaves

were borne in whorls or circles at the nodes of the side branches, there being usually nine leaves in each whorl. These are about half an inch long, very narrow, and pointed at the ends. The leaves are all of the same size, and appear to have been unconnected at the base, though there is some uncertainty on this point.

It will be recognized at once that the whorls of leaves are strikingly like the leaves of the Paleozoic annularias already described as the foliage of the calamites. There is, however, a notable difference: in the ancient annularias the leaves in a whorl are not all of the same length. There is also another possible difference. In *Annularia*, the leaves are more or less joined at the base instead of their being possibly free at the base as in *Neocalamites*. As all the specimens of *Neocalamites* thus far found are preserved as impressions, we have no means of knowing about the internal structure of the stems and branches, an unfortunate circumstance, since knowledge of the structure would doubtless explain much that is now only to be guessed at.

There are several other kinds of *Neocalamites* found in the Old World, in fact the first to be made known came from southern Sweden. It is also found in France, and at Tonkin. There is a closely related plant known as *Annulariopsis* which is even more like its ancient relatives, since it has the leaves of a whorl of very uneven length.

There was also a group of plants that lived in the Richmond Basin, and in many other parts of the world as well, during Triassic time, that included some of the forerunners of what was to develop into a very important group in the succeeding Jurassic and Cretaceous epochs, but which has now dwindled to comparative unimportance in the world of living plants. These are known as cycads.

As these cycads are to play such an important and interesting rôle, we may stop at this point and make the acquaintance of some of those still living, and then we shall be the better able to turn back and understand and appreciate the ancient forms.

Cycads belong to the group of gymnosperms, that is, plants that do not have a closed ovary, but have the ovules and seeds naked on a scale or some other sort of a transformed leaf. The mature fruit is usually in the form of a cone, of which more will be said

later. The cycads are palm-like or fern-like plants with a woody stem or trunk that is almost never branched. In some kinds the root-like trunk does not rise above ground, while in other kinds the trunks may be from twenty to fifty or even sixty feet high (see *Figure* 52) and a foot or more in diameter, bearing at the summit a crown of large handsome pinnate leaves, or leaves that

FIG. 52. Tall unbranched and branching trunks of a living cycad (*Cycas revoluta*) from Japan. After Wieland.

are cut up into numerous narrow segments or leaflets. The leaves are curled up in the bud (circinate), as are the leaves of ferns. The bases of the leaves remain on the trunks for a very long time and make a sort of armor which surrounds and protects them, and they sometimes live to a great age. Professor Chamberlin, of the University of Chicago, who has visited and studied the cycads in many parts of the world, gives a picture of one only six feet in height that is believed to be a thousand years old, and doubtless many live to be still older. Some of the leaflets of the different kinds are shown in outline in *Figure* 53.

In the living cycads the male and female cones are always produced on separate plants. They are usually very much alike in appearance, though the male cone is smaller than the female, which is of great size in some species, reaching a length of nearly three feet and weighing, it is reported, nearly a hundred pounds.

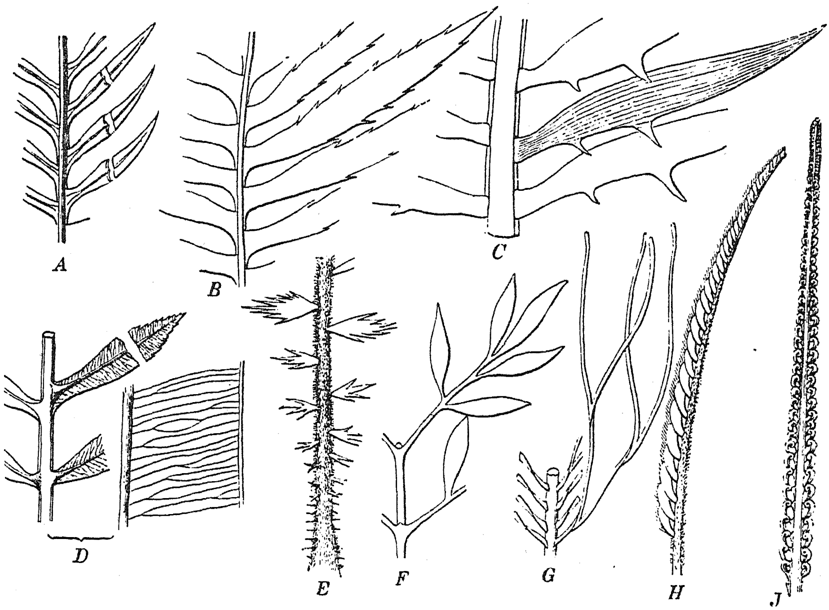


FIG. 53. Leaves in outline of genera of living cycads, introduced for comparison. *a. Cycas*; *b. Dioon*; *c. Encephalartos*; *d. Stangeria*; *e. Encephalartos* (lower part); *f. Bowenia*; *g. Macrozamia*; *h, j.* Prefoliation of *Ceratozamia* and *Cycas*. All much reduced. After Engler and Prantl.

The cones are often bright-colored—yellowish or orange—and make a very striking appearance as they stand upright at the summit of the trunk surrounded by the circle of dark green drooping leaves. We must, however, not overlook one exception to the cone-bearing habit. In the genus *Cycas*, which is the one that gave its name to the group, the male flowers are produced in a cone, but the female organs are leaf-like bodies that form a circle around the summit of the stem just like ordinary leaves, and bear the huge bright scarlet seeds on their edges.

In the cycads the pollen falls directly on the naked ovules, there being no special organs to catch and hold it as in ordinary

flowering plants. There is, however, a special cavity at the tip of the ovule, called the pollen chamber, in which the pollen collects.

The present-day cycads are almost entirely confined to the southern hemisphere. There are about seventy-five kinds (species) disposed among nine genera, of which four (*Zamia*, *Ceratozamia*, *Microcycas*, and *Dioon*) are natives of the New World; two (*Macrozamia*, and *Bowenia*) live in Australia; two (*Encephalartos* and *Stangeria*) in southeast Africa; and one (*Cycas*) extends from Japan to Australia.

Only two cycads are natives of North America north of Mexico, these being little species of *Zamia* living in southern peninsular Florida, where they are called comfort-root or coontie. The stem does not appear above ground but sends up a crown of leaves with numerous narrow, sharp-pointed leaflets. There are several other kinds of *Zamia* found in Mexico and the West Indies, and Mexico is also the home of several much larger kinds that produce erect trunks with the usual crown of handsome leaves. Perhaps the best known is *Dioon edule*, with a trunk from three to six feet tall and leaves three or four feet long with often two hundred narrow, acute leaflets. It produces large chestnut-like seeds that are boiled or roasted and eaten. From the stems there is produced the valuable food known as sago. Other kinds of Cycads in many parts of the world also yield sago, whence they are often called sago-palms, though they are of course not at all related to the true palms.

With this short account of the living cycads as a background, we are better able to go back and take up the fossil forms and try to get an understanding of their progress down through the ages. The cycads must have had their actual beginning during late Paleozoic time, but our understanding of them at this stage is not very satisfactory. But by late Triassic time they had become firmly established, and had been split up into numerous forms, many of which had already spread widely over the world. Thus in the Richmond Basin, and in beds of similar age in nearby states, about forty species of cycads have been found. These are known only from impressions of the foliage, and it might as well be confessed that the foliage does not always give as complete a story of the life history of the plants as we could wish. The size of the plants, the manner in which they branched—if they did

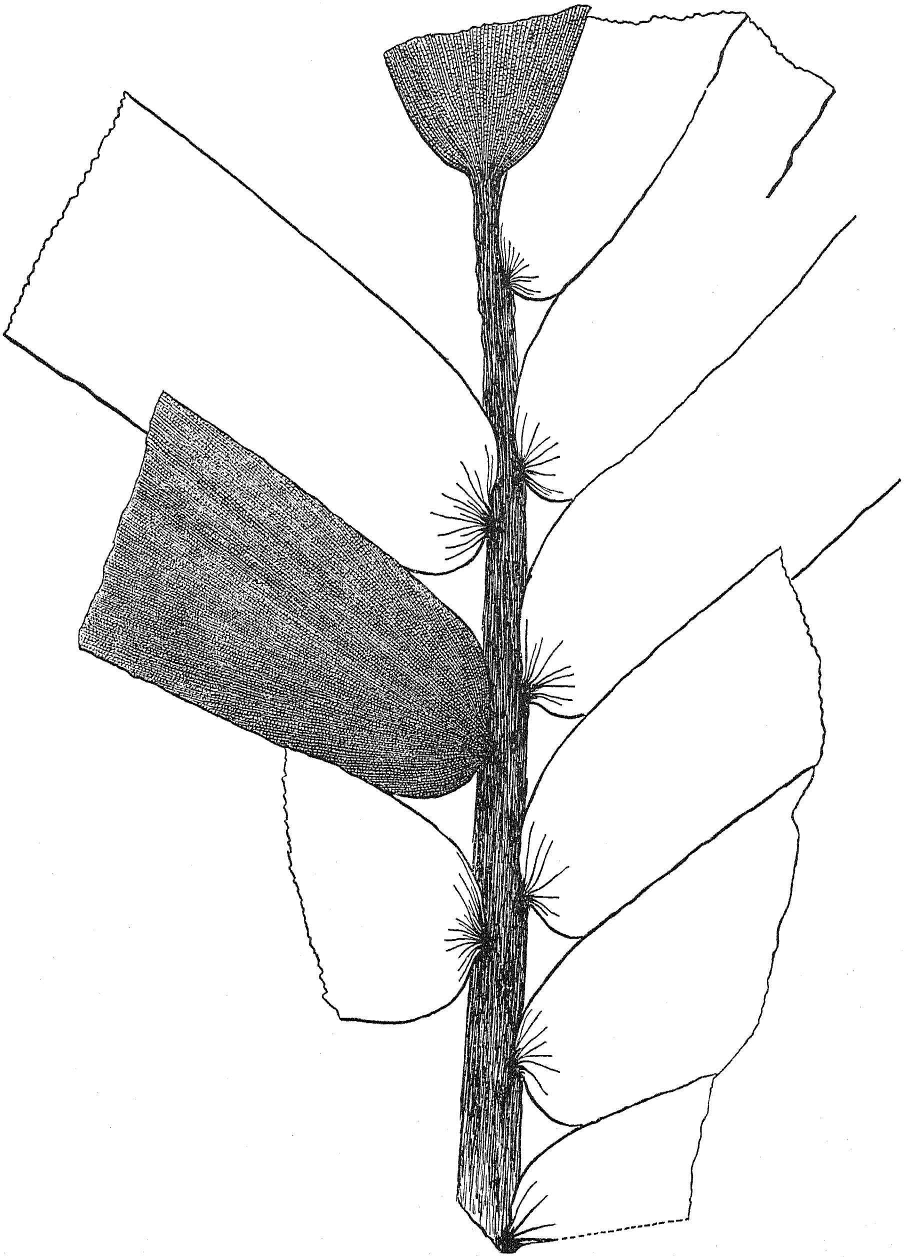


FIG. 54. Fragment of large cycad leaf (*Sphenozamites rogersianus*) from Triassic of the Richmond Basin, Virginia. One-half natural size. After Fontaine.

branch—and above all their organs of reproduction, are practically unknown. But from the undoubted similarity to the foliage of certain living cycads, it is more than reasonably certain that they are cycads, and we may so regard them.

One of the most abundant forms found in the Richmond area is called *Sphenozamites rogersianus*. A small portion of a leaf about one-quarter natural size is shown in *Figure* 54. The leaves were of very large size, ranging from three to four feet or more in length and from sixteen to twenty inches in width. The leaf-stalk or petiole was a woody rod half an inch in diameter, and on the upper third of its length it bore these huge leaflets, that in some cases reached a length of nine inches and a width of over four inches. These leaflets were not exactly in pairs, but were borne on opposite sides of the petiole. They are blunt or almost "square cut" at the tips, but the base was sharply contracted into a short point of attachment. The veins in the leaflets all originated at this point of attachment, and spread apart and forked a number of times in the lower portion and then ran parallel to the apex of the leaflet.

Sphenozamites, with its crown of huge leaves, must have been a very striking feature among the plants of its time in Virginia. It is the only one of its kind known in the Mesozoic rocks of North America, although several near relatives of it are found at a number of places in the Old World. The genus *Sphenozamites*, or something close of kin to it, appears to have started in the late Paleozoic, but it ran its course and had died out before Cretaceous time. Its great abundance in the Triassic swamps of Virginia would seem to indicate that it was one of the important contributors to the formation of the great coal beds of the region.

Equally abundant and perhaps almost as striking, though in a somewhat different way, were two other cycads that lived together with the last in the Virginia region. They are called *Ctenophyllum* and are shown greatly reduced in *Figure* 54. The larger one (*Ctenophyllum grandifolium*) had leaves three or four feet long and more than eighteen inches wide, but instead of the broad leaflets as in *Sphenozamites*, it had a great number of narrow leaflets half an inch wide and twelve inches long. There was also another marked difference. Instead of having the base contracted into a slender point, the leaflets were attached to the petiole by

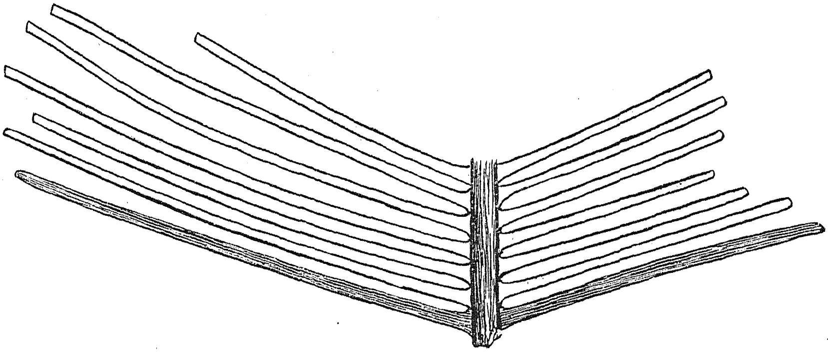


FIG. 55. Fragment of leaf of cycad (*Ctenophyllum braunianum*) from Triassic of the Richmond Basin, Virginia. After Fontaine.

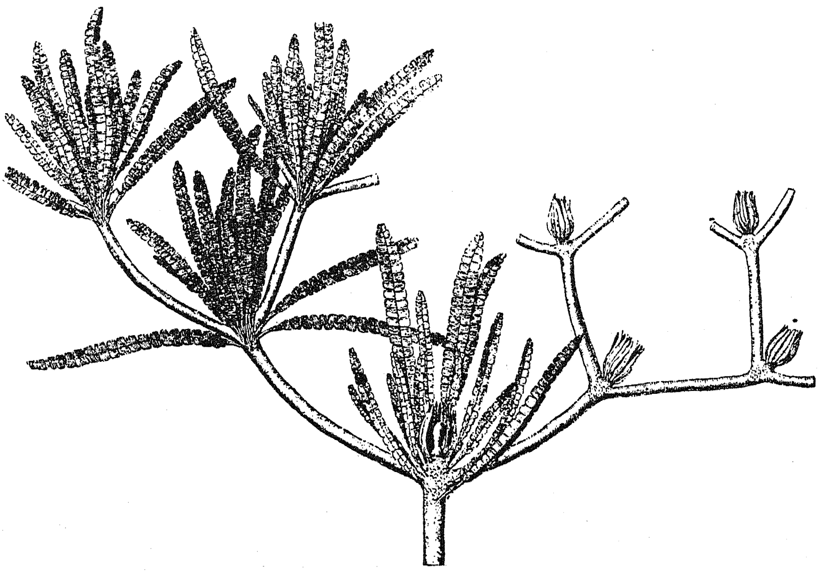


FIG. 56. Restoration of *Wielandiella*, showing leaves and flowers, from the Triassic of Sweden. After Nathorst.

their whole width, and had the veins unforked and running parallel the length of the leaflet. The petiole, too, was different, being apparently fleshy rather than woody.

The other species of *Ctenophyllum* (*Ctenophyllum braunianum*) (*Figure 55*) was a sort of "smaller edition" of the larger

one, its leaves being only about two feet long, with the leaflets three or four inches long, and hardly an eighth of an inch wide. Otherwise they were very much alike.

There are several other cycads that lived in the Virginia area at this time, but as most of these are rare, indeed some of them are known from only one or two specimens, it is presumed that they were neither conspicuous nor very important.

As affording some knowledge of the general appearance of these earlier cycads, including both foliage and fruiting organs, mention may be made of a remarkable plant described from the upper Triassic rocks of Sweden under the name of *Wielandiella*, and shown in restoration in *Figure* 56. It had an elongated stem, half an inch or less in diameter, which was repeatedly forked, and had the leaves clustered just below the forks, the stems otherwise being naked. The small narrow leaves were only about three inches in length, and were cut into pinnately arranged segments. These leaves belong to a genus called *Anomozamites*, a so-called form genus based originally on unattached leaves. Whether all the leaves of this type are really congeneric, or were borne on plants similar to *Wielandiella*, is not known, but it is at least a suggestion.

The flowers were small, pear-shaped, nearly sessile affairs, closely surrounded by narrow bracts, and are known in two forms, though this may be due to different stages of development, or possibly different states of preservation. In one there appears to be a series of reduced bracts (sporophylls) bearing numerous pollen grains (microspores). In the other there is evidence of seeds or ovules, but they are so immature that their nature cannot be made out with certainty.

Several other cycad-like fructifications have been described from the Triassic rocks of Sweden and elsewhere, but they are so fragmentary and poorly understood that their further consideration may be omitted.

Chapter IX

THE PLANTS OF JURASSIC TIME

ALTHOUGH rocks of Jurassic age were first recognized and studied in England, the period is named from the Jura Mountains, a short chain of mountains that separates France from Switzerland, where also these rocks are well developed. During Jurassic time the land area, especially in North America, was very extensive, and in places very high, so that the rocks were rapidly cut down (eroded) and the resulting sediments poured into the seas. On the Pacific coast, however, there is evidence to show that the Jurassic sea extended inland from Alaska to Mexico, reaching at one time even as far east as Colorado. The story is much the same for other parts of the world, and there appear to have been practically continuous land areas, some of which are now separated by hundreds of miles of open sea. The climate during Jurassic time was mild and was much the same over a large part of the world, and this fact, together with the wide extent of the land, permitted the land plants to spread widely, more widely, it is believed, than any other known flora, either fossil or living. The Jurassic flora is known from Franz Josef Land, 82° N. or within 8° of the North Pole, to Hope Bay, Graham Land, 63° S., and from western Alaska entirely around the earth to eastern Australia, or through more than 155° of latitude, and more than 230° of longitude. Notwithstanding its almost world-wide distribution, the Jurassic flora is not an especially rich one, or at least so far as it has been made known, for hardly more than five hundred species have thus far been found. There are, however, some very remarkable and interesting plants among them.

The principal kinds of plants which lived during Jurassic time were ferns, cycads, and conifers. There were some other kinds, it is true, such as algae, scale-mosses (*Marchantites*), small horsetails, and lycopods, but they were apparently few in number, and, moreover, are so poorly preserved that they are but imperfectly known. The most abundant and characteristic plants of the

time were the cycads, and on this account the Jurassic has often been called the "Age of Cycads." It is thought that at least two out of every five species then living were cycads, and, as Doctor Scott tells us, if this proportion held among living plants, we should have some 40,000 different kinds of cycads instead of only about seventy-five.

As the cycads (see *Figure* 57) were the most abundant element in this flora, we may appropriately begin our account with a picture of some of the more interesting ones. A brief description of the appearance and present distribution of the living cycads was given in the last chapter, and need not be repeated.

It will be remembered that the Triassic cycads are known only or mainly from impressions of the foliage, with very little indication of the trunks which bore these leaves, or of their flowers or fruits, though a number of seeds supposed to have belonged to them have been found. Many of the types of Triassic cycads lived on into Jurassic and probably later time, and perhaps finally developed into the group now living. Others also had their beginning in the Triassic, or possibly earlier, and lived through the Jurassic and well into the Cretaceous, but they had all practically disappeared by or before the middle of the Cretaceous.

The most abundant and diversified of the Jurassic cycads are based largely on impressions of leaves, and are included in so-called form genera, but before describing these attention may be directed to a group of very peculiar cycads known as the williamsonias. They are very different in appearance from the short, globular-trunked forms (*Bennettitaceae*) of early Cretaceous time, as well as from living forms. They had tall, slender, more or less branched stems covered with rhomboidal leaf-scars, and surmounted by a circle of large pinnate leaves two feet or more in length. They produced flowers that in some forms were nearly five inches in diameter, and in some, possibly in all, the male and female organs were in separate flowers. A male flower, seen in *Figure* 58, shows a circle of a dozen or more large, flat stamens joined at their bases into a sort of disk, and each bearing a double row of pollen sacs on its upper surface. The female flower was a more complicated affair, but evidently made on the plan of the flower in the Cretaceous *Bennettitaceae* above mentioned, and to be described later.

FIG. 57. Idealized upper Jurassic landscape, showing mainly different types of cycads. After Saporta.

Closely related to the williamsonias is a curious plant from the middle Jurassic beds of Yorkshire, England, called *Williamsoniella*, and seen in restoration in *Figure* 59. It had a slender, repeatedly forking stem, about an inch in diameter, that bore scattered simple leaves of the type of the genus *Taeniopteris*, and in the forks of the stems the peduncled or long-stalked fruits, one of which about half natural size is shown on the right of the figure.

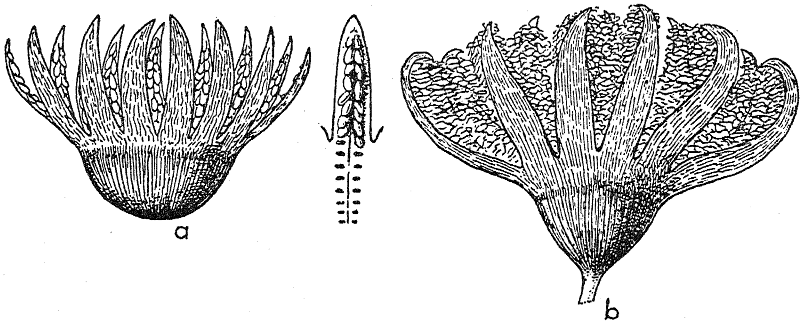


FIG. 58. Restoration of the male or pollen-bearing "flowers" of Jurassic cycads. *a. Williamsonia whitbyensis*; *b. Williamsonia spectabilis*. One-half natural size. Restored by Nathorst.

Williamsoniella is obviously related to the plant already described as *Wielandiella*, from the upper Triassic beds of Sweden, but differs in a number of particulars, such as having scattered simple leaves, instead of pinnate leaves clustered about the forks of the stems, and in the fruiting organs.

These plants are so obviously related among themselves, and are so different from the other groups of cycads, that it is necessary to place them in a separate family, which takes the name *Williamsoniaceae*. The two last-mentioned genera are very rare and of very limited known distribution, ranging in age from the upper Triassic through the Jurassic and well into the Cretaceous. They are especially abundant in the English Jurassic, and in India, but were apparently uncommon in the North American beds of this age. As might be supposed, there are considerable differences in the various flowers, though all agree essentially with the one described and figured above.

We may now return to a brief consideration of the form genera,

to which attention has already been called. They were very abundant, and altogether constituted the most conspicuous element in the Jurassic flora. They are found from Arctic to Antarctic, and

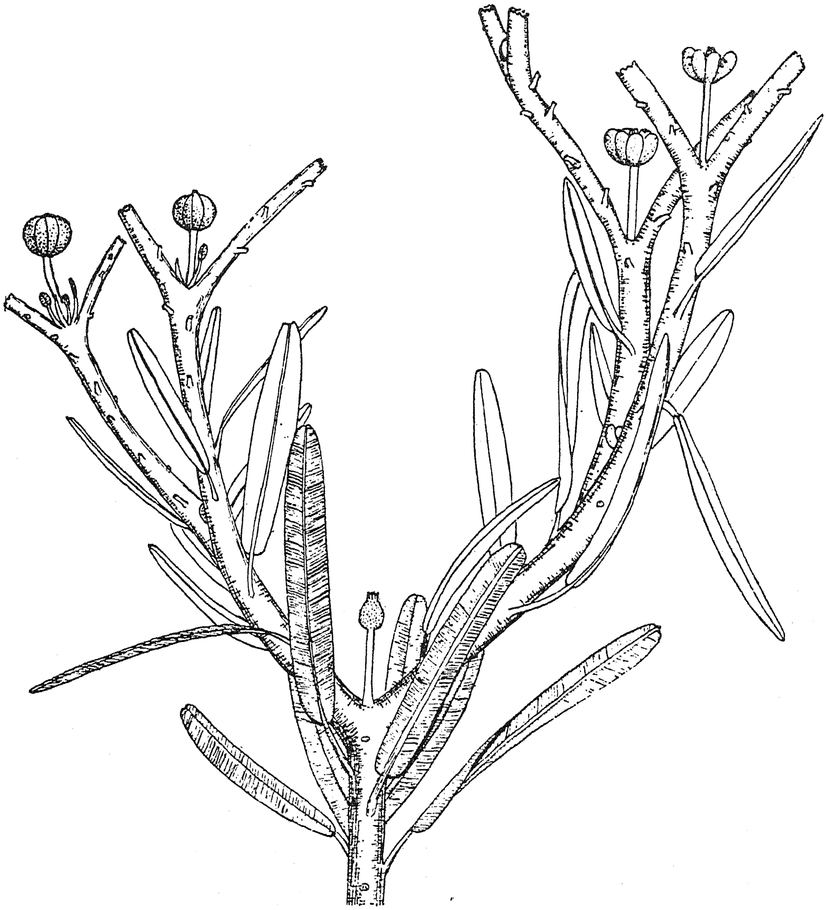


FIG. 59. Restoration of Jurassic cycad (*Williamsoniella coronata*) from Yorkshire, England. After Thomas.

every area where these rocks are exposed is found to have its more or less full quota of forms, some, indeed, ranging over several continents. They are based on impressions, mainly of leaves, but in a few cases on isolated fruiting organs, and as the plants which bore them are unknown, it has been necessary to bring them

together into these artificial groups, or so-called genera of convenience. Of these are upwards of twenty "genera," and approximately two hundred "species," though probably not all are valid forms, as there are some differences of opinion among students as to generic and specific limits. The bulk of them are supposed to belong—and in fact probably did belong—in the family *Williamsoniaceae*, as this is the only family that was much in evidence at the time, and moreover, in the few instances in which the leaves were found attached, or in close association with the stems or trunks, they are referable to one or another of these form genera. (See *Williamsoniella* and *Wielandiella.*)

These leaves were in general striking and handsome leaves, from a few inches to two or more feet in length, and often very perfectly preserved, indicating that they were thick and tough in texture, and hence not readily injured or torn when they were buried. The several genera are founded largely on the outline and nervation of the leaves, and in these features they range widely, as may be seen from those shown in outline in *Figure* 60.

The conifers or, perhaps better, the coniferophytes, that lived during Jurassic time, were evidently abundant and considerably diversified, though it is doubtful if any was very large. They could not compare, for instance, with the splendid forests of later Paleozoic time. It is thought reasonably certain that at least three living groups of conifers (tribes or families, they are variously called) were represented in Jurassic time, but as they are known mostly from impressions, and mainly lack the structural and fruiting characters, not all can be considered as fully authenticated.

The presence of the *Araucariaceae*, as typified by the modern *Araucaria*, or Norfolk Island pine, seems to be pretty firmly established, being based on petrified wood showing the characteristic structure and markings, as well as leafy twigs, and one-seeded cone-scales. It will be recalled that the wood of the Carboniferous genus *Cordaites* also exhibits markings on the wood cells that are at least strongly suggestive of *Araucaria*, and the wood of the fossil forests of Arizona is araucarian. It therefore seems a reasonable assumption that the Jurassic forms may possibly represent a step between this ancient stock and the modern representatives.

There are several other Jurassic genera that show more or less clearly their kinship with *Araucaria*, among them one known as

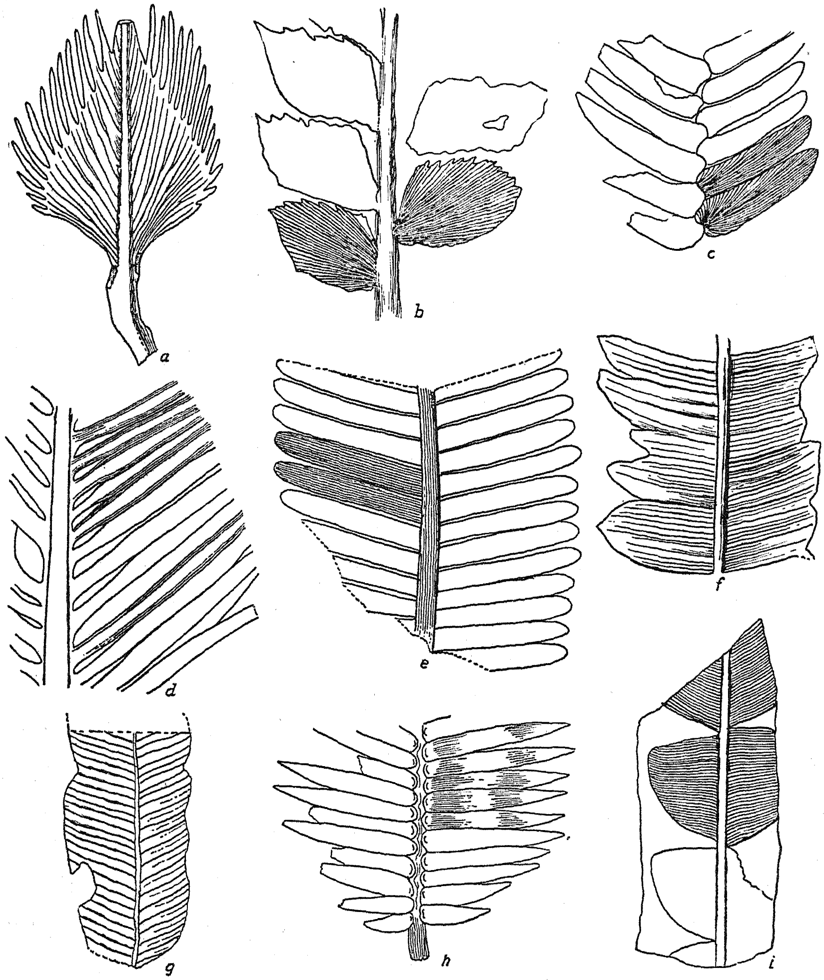


FIG. 60. Outlines of leaves of several form genera of cycads. *a. Cycadospadix*; *b. Sphenozamites*; *c. Otozamites*; *d. Cycadites*; *e. Pterophyllum*; *f. Anomozamites*; *g. Nilssonia*; *h. Zamites*; *i. Anomozamites*. All greatly reduced.

Elatides, which was described from Spitzbergen, and since found to be quite widely distributed. The branches bore spirally arranged, somewhat hooked leaves not unlike those of some sequoias, and oval cones an inch or more long and about a fourth of an inch broad, apparently with a single seed on each cone-scale.

Pagiophyllum (see *Figure* 61 *a*) is another coniferophyte that was widely distributed during Jurassic time. It may have begun as early as Permian time, and survived through the Cretaceous. It is known almost entirely from impressions of leafy branches.

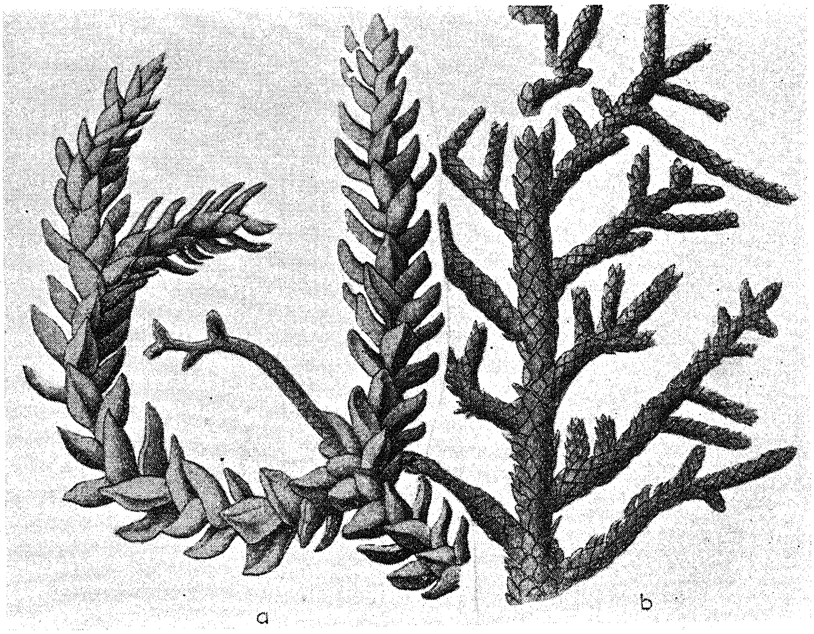


FIG. 61. Leafy branches of Jurassic conifers. *a. Pagiophyllum rigidum*; *b. Brachyphyllum moreanum.* After Saporta.

These, as may be seen from the figure, have the thick leaves somewhat spreading at the tips. *Pagiophyllum* resembles the form next to be described, and indeed has not infrequently been confused with it. It is also closely similar to a living species of *Araucaria.*

One of the most abundant and widely distributed of Jurassic conifers is called *Brachyphyllum*, known almost entirely from the leafy shoots (see *Figure* 61 *b*). The branches are pinnately arranged in one plane, thus producing a flat spray, and spirally disposed leaves, which are thick, triangular or hexagonal in shape, and pressed closely to the branch. Some specimens bearing cones have been found, but they are so imperfectly preserved that the

characters cannot be made out, and a Cretaceous species from Staten Island, New York, showing structure, is said to have affinity with *Araucaria*, but whether all species of *Brachyphyllum* bear out this relationship is not known. In a general way *Brachyphyllum* suggests the living cypress (*Cupressus*), and for this reason it is by some often placed in the same living family with it, and by others in a family by itself. It began in Triassic time, and continued through the Jurassic, and well into the Cretaceous before it disappeared.

Specimens that have been identified as *Sequoia* have been found in Jurassic rocks, but as they are based on foliage shoots or branchlets, their position is somewhat uncertain. There are also several others of unknown relationship, though from the form and disposition of the foliage they are thought possibly to belong with or near the maidenhair trees (*Ginkgo*).

Another rather striking plant, known as *Podozamites*, was abundant and widely distributed during the Jurassic. It began in the Triassic and survived well into the Cretaceous. It has, as may be seen from the figure (*Figure* 62), a slender axis or petiole with numerous scattered pinnately disposed leaflets or segments, which are narrowed at the base, but in shape may be narrow and sharp-pointed, or broader and obtuse at the apex. There are numerous veins which diverge from the base, and, in exceptionally well-preserved specimens, the base of the petiole may be enclosed by a number of overlapping scale-leaves.

There has been a good deal of discussion and difference of opinion as to the relationship of *Podozamites*. When first named and described it was supposed to be a cycad, more or less closely related to the living genus *Zamia*, but the conviction has been growing of late that it is possibly a conifer or, perhaps better, that it is intermediate between these two groups. The best known and most widely distributed species (*Podozamites lanceolatus*) has narrow, sharp-pointed leaflets, which are easily detached, and probably have not always been correctly identified, as it could easily be confused with other similar forms.

One of the most interesting, and certainly one of the most abundant and widely distributed trees that lived during Jurassic time, is the ginkgo or maidenhair tree. It is represented at the present time by a single species (*Ginkgo biloba*) living in China

and Japan, where it is held sacred, and planted about the temples, in fact, it is more or less doubtful if it lives anywhere in a truly wild state. Be this as it may, however, it is no longer likely to disappear, as it has been carried to many parts of the world, where it is grown as an ornamental or shade tree. In the District of Columbia, for instance, it is planted as a shade tree along many

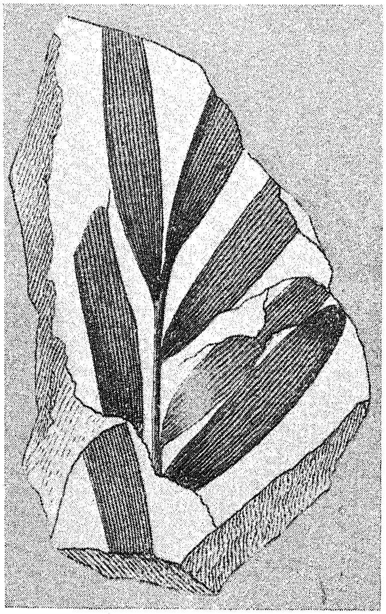


FIG. 62. Foliage of supposed cycad (*Podozamites lanceolatus*) from the Jurassic of Siberia. After Heer.

streets, where it is perfectly hardy and fruits freely when of sufficient size and age.

The *Ginkgo* is a pyramid-shaped tree with a smooth trunk two or three feet, or sometimes more, in diameter, and eighty or a hundred feet high. It has broad, flat, leathery leaves, which fall in the autumn like the leaves of a maple or elm, with forking veins much as in the leaves of the common maidenhair fern (*Adiantum*), whence its name of maidenhair tree. The fruit is a globular hard-shelled nut an inch long, with a thin outer flesh which has an exceedingly strong, disagreeable odor. *Ginkgo* used to be placed with the true conifers, but a few years ago some

facts were discovered regarding its method of fertilization, which place it far outside the typical conifers, and it now enjoys the unique distinction of representing a species, a genus, a family and an order, all in one.

This distinction is based principally on the manner in which the seed is fertilized. The female organ or ovule possesses a well-defined pollen chamber at its apex for the reception of the pollen

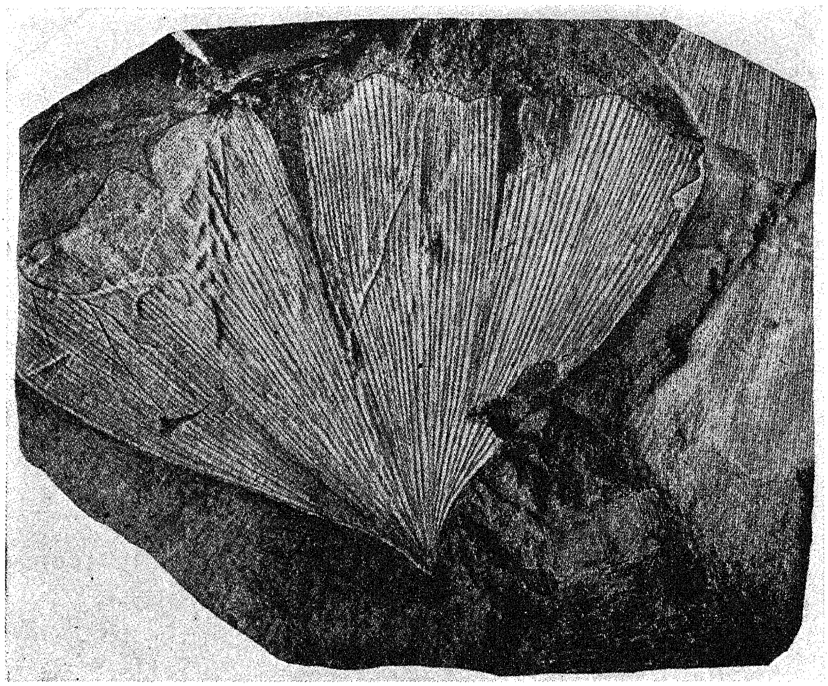


FIG. 63. Leaf of maidenhair tree (*Ginkgo digitata*) from the Jurassic of Oregon. After Knowlton.

grains. A pollen grain germinates, producing a so-called pollen tube, and just before fertilization takes place each tube develops two large ciliate spirally coiled male cells (spermatozoids), which enter and fuse with the egg cell of the ovule, thus accomplishing fertilization. This method of fertilization by motile male cells serves to distinguish *Ginkgo* from all members of the pine family and immediate allies.

Ginkgo can probably lay claim to being the oldest tree now living, that is to say, it has come down to us for perhaps ten million years so little changed that it is difficult, if not indeed impossible, to find any essential differences in the leaves. There may have been differences in the wood, flowers or fruits, but as these have rarely been found, or at least have not been recognized as such, we have to depend mainly on the leaves, and although many supposed species have been named and described, they can

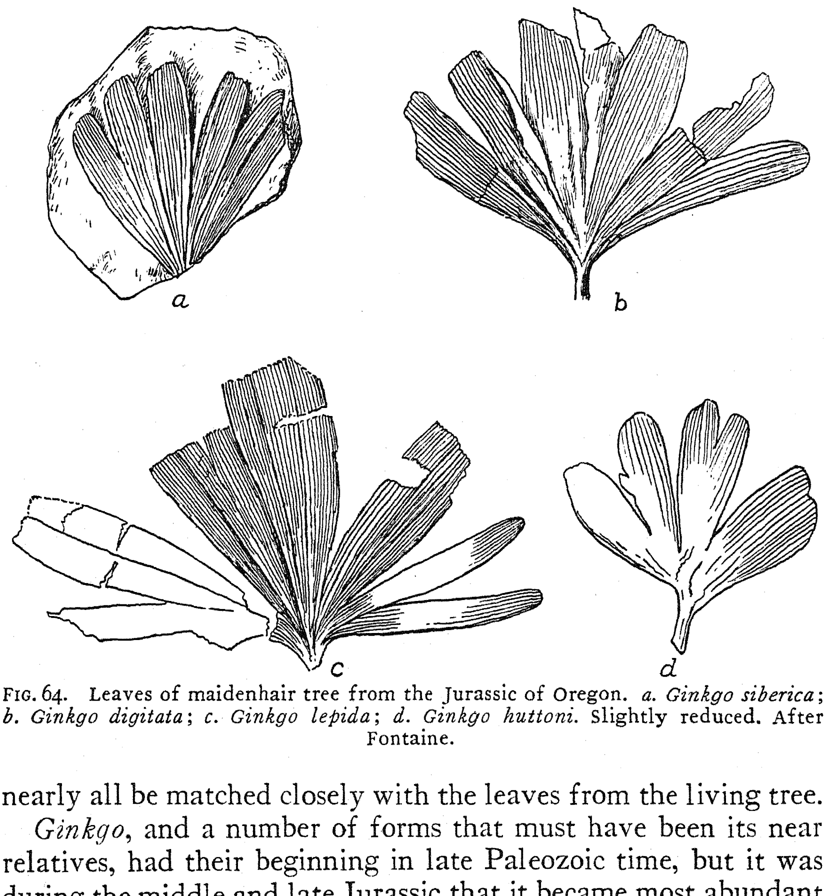


FIG. 64. Leaves of maidenhair tree from the Jurassic of Oregon. *a. Ginkgo siberica*; *b. Ginkgo digitata*; *c. Ginkgo lepida*; *d. Ginkgo huttoni.* Slightly reduced. After Fontaine.

nearly all be matched closely with the leaves from the living tree.

Ginkgo, and a number of forms that must have been its near relatives, had their beginning in late Paleozoic time, but it was during the middle and late Jurassic that it became most abundant and most widely distributed, especially in the northern hemisphere. In certain beds in Oregon, for instance, great, splendidly

preserved leaves are found in hundreds, and in many parts of Alaska, even in the barren lands bordering the Arctic Ocean, *Ginkgo* leaves are found. On Franz Josef Land (82° N.), and in western Greenland, as well as many places in Siberia, and at Yorkshire, England, these leaves are found, showing that perhaps the same species once spread throughout this vast area.

Figure 63 shows a fine *Ginkgo* leaf from the Jurassic beds of Oregon, and *Figure* 64, a series of leaves in outline from the same beds.

Evidently quite closely related to *Ginkgo*, and having almost as wide a distribution is the leaf shown in *Figure* 65, that is known

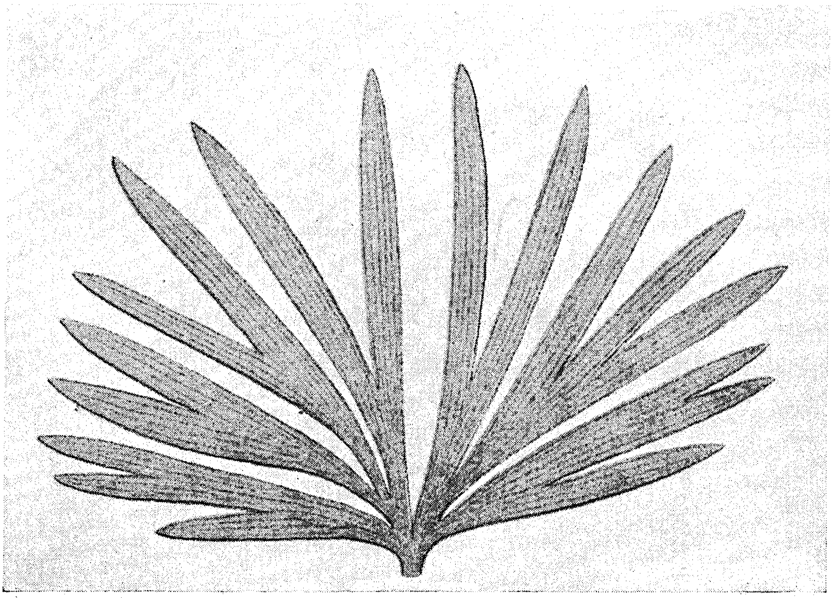


FIG. 65. Leaf of *Baiera*, a ginkgo-like tree, from the Jurassic of France. After Saporta.

as *Baiera*. The outline of the leaf is much the same as in *Ginkgo*, but it is cut into many narrow segments. The size of the tree which bore these leaves is not known, as only the leaves have been certainly recognized.

In summing up the probable appearance of the vegetation of Jurassic time, Berry says: "A picture of the flora at any time

during the Jurassic would show nothing like the lofty forests of the Paleozoic or of Tertiary and modern times. The Jurassic floras, whether of swamp or upland, as known, consist primarily of ferns, cycads, and conifers. The ferns were all forms of moderate size. None of the cycad-like forms, so characteristic of this age of earth history, were lofty; probably none were as tall as an old existing individual of *Cycas*, and the Jurassic cycads are more comparable in appearance to what is commonly denoted by the term 'scrub.' Rising above the general low level of this scrub were the various *Coniferophytes*, which may have predominated in more or less pure stands at certain localities, and among which the Jurassic representatives of the maidenhair tree (*Ginkgo*) stand out prominently."

Chapter X

PLANT LIFE IN CRETACEOUS TIME, AND THE COMING OF FLOWERING PLANTS

THE Cretaceous is the uppermost or latest of the three major divisions or periods of the Mesozoic era and is itself divided into two parts, called, respectively, the Lower Cretaceous and the Upper Cretaceous. In Lower Cretaceous time the continents were comparatively low, especially in the northern hemisphere, and the period as a whole is particularly remarkable from the fact that it witnessed wide expansions of the sea over the land in many parts of the world. At first the North American continent was very little changed in outline along the east coast, but on the west coast there were marked changes. A high peninsula developed from Oregon southward to southern California, and a broad area of the sea covered much of the interior portions of California and Oregon. In the interior of the continent also the land was sinking.

Early in Upper Cretaceous time the continent was further submerged over extensive areas. Thus the sea spread on the Atlantic and Gulf coasts as a broad belt from Cape Cod to Texas, and in the present Great Plains and Rocky Mountain region there was developed a great shallow inland sea, several hundred miles wide, connecting the Gulf of Mexico with the Arctic Ocean, and dividing the continent into a large eastern and a much smaller western portion. By the close of Upper Cretaceous time, however, this vast interior region was again elevated, the Rocky Mountains were built up, and the sea pushed back approximately to its present position.

As might be expected from the widespread extensions of the seas over the land, the beds deposited were mainly laid down in marine or brackish waters, and hence were poorly fitted to preserve the remains of land plants. Fortunately, however, there were quite thick fresh water deposits laid down in many places on the land, and from these a considerable representation of the plant life of the time has been recovered, though doubtless it is

only a fraction of the numbers that were then living. The plants of early Cretaceous time were mainly ferns, cycads, and conifers, the types of which had lived on from late Jurassic time, but were fated to die out by or before the beginning of the Upper Cretaceous.

The account of the early Cretaceous floras may well begin with a description of some rich deposits of plants in the Eastern United States, where, as we shall see later, there apparently was laid the scene of some extremely important events in the plant world. Covering a considerable area, mainly in Maryland and Virginia, there are beds of clays, sands and sandstones, that make up what has been called the Potomac beds, so named from the Potomac River, which separates these two states. These beds are divided into three quite distinct divisions, which together represent practically the whole of Lower Cretaceous time in this region. The lowest or oldest of these three divisions—called the Patuxent—contains a flora of about one hundred species of plants, of which about thirty-five are ferns, twenty-five cycads, and over forty are conifers.

Ferns were evidently very abundant in Patuxent time, for in some of the clay beds their remains or impressions make up a thick, tangled mass, almost to the exclusion of other kinds of plants. They were all of small size, probably few of them being more than two or three feet high.

Patuxent time seems to have been a meeting ground of the old and the new. That is, some of these plants had lived on from Jurassic or earlier time, and others were evidently the foundation of modern living groups.

One of the most interesting ferns, called *Schizaeopsis*, is shown in restoration in *Figure* 66. It has the fruit at the ends of the veins and projecting beyond the margin of the frond. The only living North American fern of this group is the so-called curly-grass (*Schizaea pusilla*) of Nova Scotia and New Jersey.

There is another strange fern, known as *Tempskya*, that probably belongs in the same family as the one just described. It was first made known in 1845 from specimens collected in Lower Cretaceous rocks in Bohemia and has since been found in France, north Germany, Russia, England, and in Maryland and Montana. It consists of a few slender stems surrounded by

a dense felted mass of adventitious roots, the whole producing what is called a false stem. The stems doubtless bore a crown of leaves at the summit, though no trace of foliar organs has yet been identified as belonging to them. The species differ greatly in size, the largest (from the Wealden beds of England) being some nine feet long and twelve inches wide. The specimen

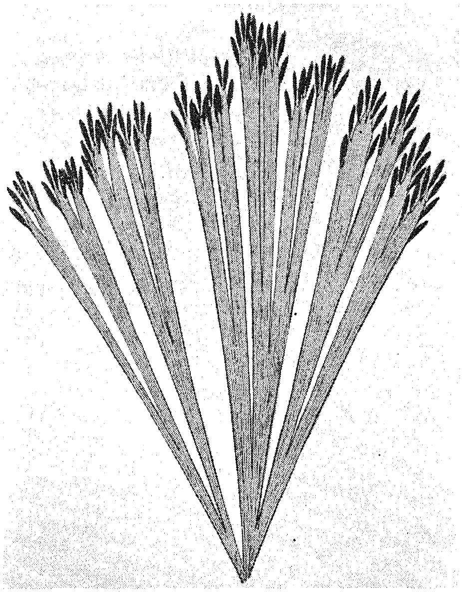


FIG. 66. Restoration of fruiting frond of fern (*Schizaeopsis americana*) from Patuxent of Maryland. One-half natural size. After Berry.

shown in *Figure* 67, from the Lower Cretaceous of Montana, is only about nine inches long. The transverse section (*Figure* 67 *b*) twice natural size shows the stems surrounded by the mass of roots and *Figures* 67 *c*, *d*, enlarged about eighty-five times, show transverse sections of a root and of two stems, the latter just after the parent stem had branched. Both stems and roots are typically fern-like in structure, and the spore-cases and spores appear to indicate the reference of the plant to the family *Schizaeaceae*.

There are differences of interpretation among students as to the position assumed by this curious plant when it was living; some, probably because the roots pursue a vertical course, re-

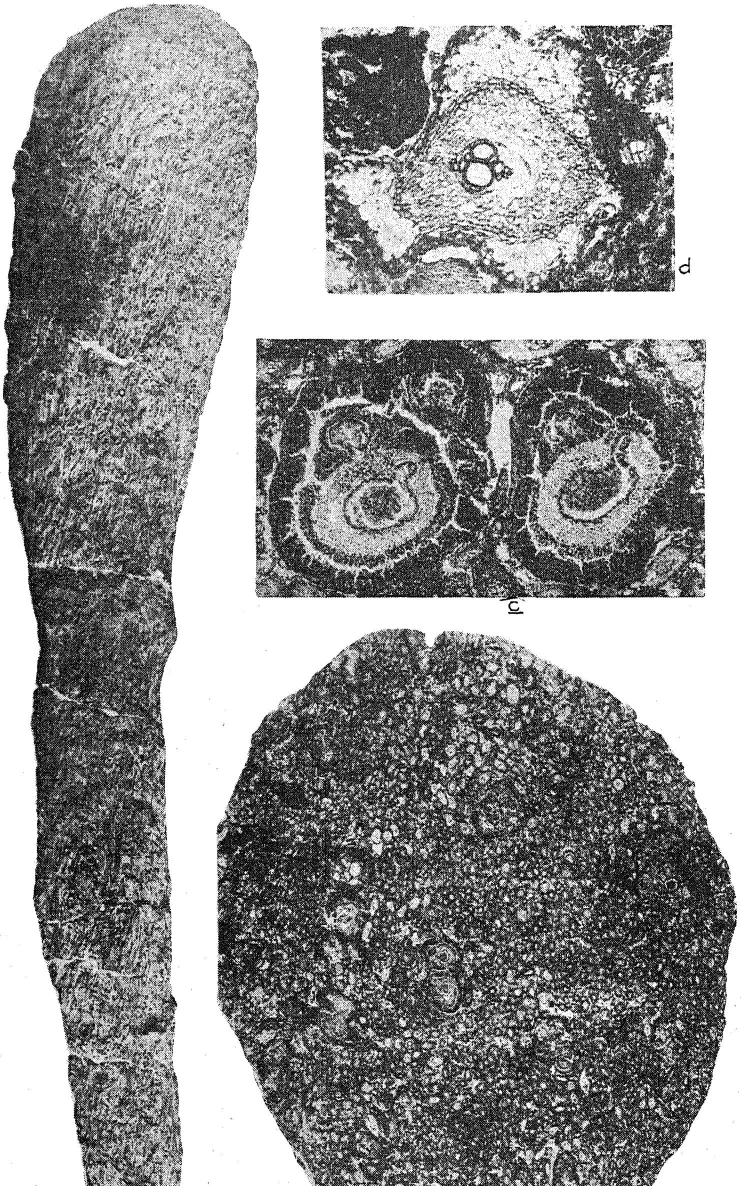


FIG. 67. A strange fern (*Tempskya knowltoni*) from the Cretaceous of Montana. *a*. Specimen natural size; *b*. transverse section showing stems and enveloping mass of roots, twice natural size; *c*. transverse section of stems, enlarged 85 times; transverse section of root, enlarged 85 times. After Seward.

gard it as having stood erect, but others think it was more or less prostrate. Dr. A. C. Seward, who studied the Montana specimen, says: "I prefer to think of it as a root-encircled bundle of stems, obconical and tapering, lying obliquely in the soil, a few of the stem-branches bearing crowded fronds near the ground-level."

The interesting group of cycads has been mentioned a number of times, and its history traced from its beginning in late Paleozoic time, through its extraordinary expansion in the Triassic and Jurassic, and reaching in many respects its culmination in early Cretàceous time. Our knowledge of the cycads thus far considered is based very largely on the foliage, with only sporadic glimpses of the structural and fruiting characters, but with those we shall now review, almost the complete reverse is true—that is, thanks to the many wonderfully preserved Cretaceous representatives, we now know the structure of the trunks, flowers, fruits, seeds, and even the embryo plantlet in the seed, but almost nothing of the leaves; in fact if it were not for some tiny unfolded leaves in the bud, we should not know positively just what kind of foliage they possessed. As these Cretaceous specimens have been more intensely studied, it has been increasingly evident that their structure, flowering, and fruiting characters are so different from the earlier williamsonias, as well as from living cycads, that they cannot be placed in either family. Therefore there has been created for them the family *Bennettitaceae* which takes its name from the trunk called *Bennettites gibsonianus*, first named and described from the Isle of Wight, some fifty years ago. Other trunks from the same locality have since been found, and as they are often hollowed out at the top, they have somewhat fancifully been called "crow's nests" by the quarrymen.

A number of well-preserved cycad trunks have been found in France, Italy and other places in the Old World, but the United States has proved to be the real treasure house for these wonderful trunks; and upwards of a thousand of them are now known. The larger part of these have been brought together in two great collections, one in the National Museum at Washington, and the other in the Peabody Museum of Yale University. They have been found in many states, but principally in Wy-

oming, South Dakota, and Maryland. They are silicified, and when they have been cut up into thin slices, they can be studied in as much detail as many of the living cycads have been studied.

The Patuxent cycads belonging to this group were evidently quite abundant, as nearly a hundred trunks or parts of trunks have been found. The Cretaceous cycads were larger than any known to have lived previously, and there is no very apparent reason why they should not have lived on to the present time, but there was evidently some fatal weakness that cut them off. Professor Wieland, of Yale University, who has spent a lifetime in their study, thinks it probable that they were crowded out into an arid or desert region, where they were stranded and so were unable to get out when more favorable times came.

Associated with these trunks are numerous leaves of cycads, but whether any of them really belong to the trunks is not known, as they have not been found connected. They are much like many of the cycad leaves mentioned under the Jurassic flora.

In connection with the Maryland cycad trunks it is perhaps opportune to present a general description of the family *Bennettitaceae*, although most of the best-known forms are found in distant regions. They are referred to a single genus (*Cycadeoidea*), and more than forty nominal species have been described.

In *Figure* 68 may be seen a group of eight of these trunks from Lower Cretaceous rocks of the Black Hills, in western South Dakota, now preserved in the National Museum, and in *Figure* 69, a single exceptionally perfect trunk from Maryland. These trunks are short, chunky, barrel-like affairs, and some of them are actually greater in diameter than they are in height, but usually the reverse is true. They range in height from twelve or fourteen inches to three or four feet, with an occasional one that may have been nine or ten feet high. They are sometimes branched, though usually there is only the solid barrel-like trunk.

Referring again to *Figure* 69, there is seen a number of small, more or less regularly three-sided holes, which mark where the leaves once grew. The active leaves formed a crown about the summit of the trunk, as they do in the living cycads. The bases of the leaves probably remained on the plant for a long time and served to protect the trunk; they were surrounded by a thick,

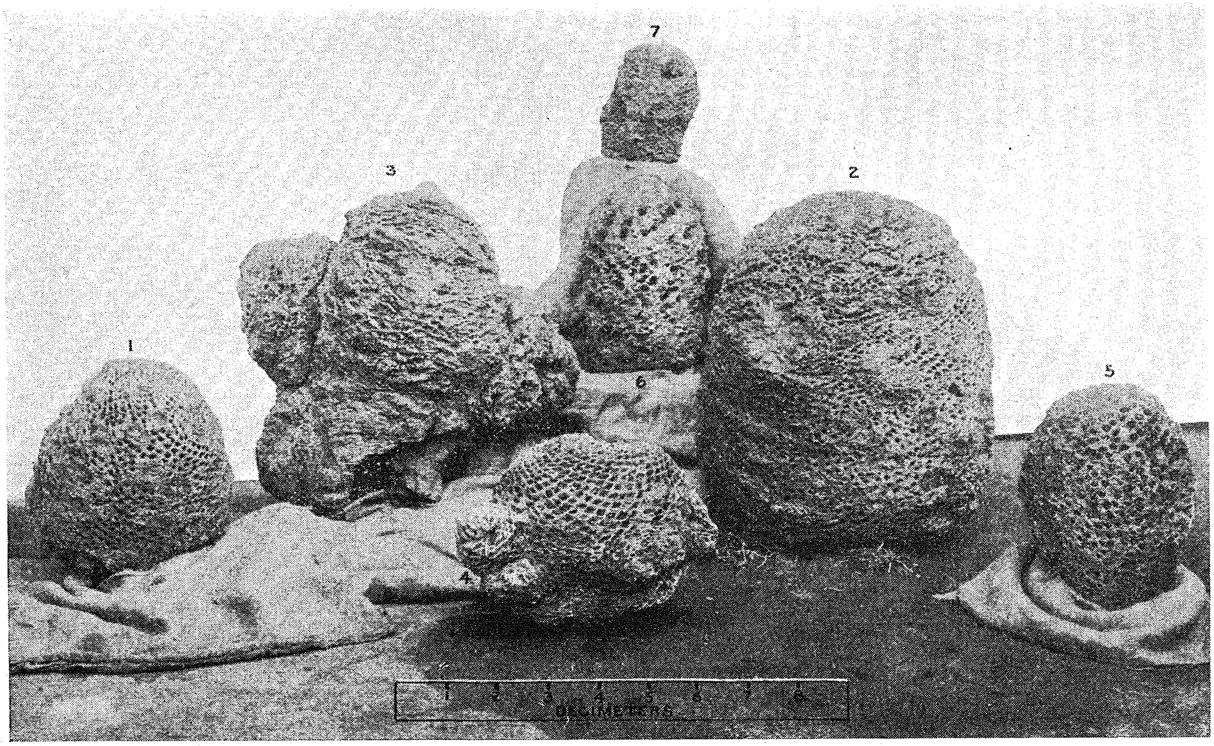


FIG. 68. Group of cycad trunks (*Cycadeoidea*) from the Cretaceous of the Black Hills, South Dakota. Preserved in National Museum. After Ward.

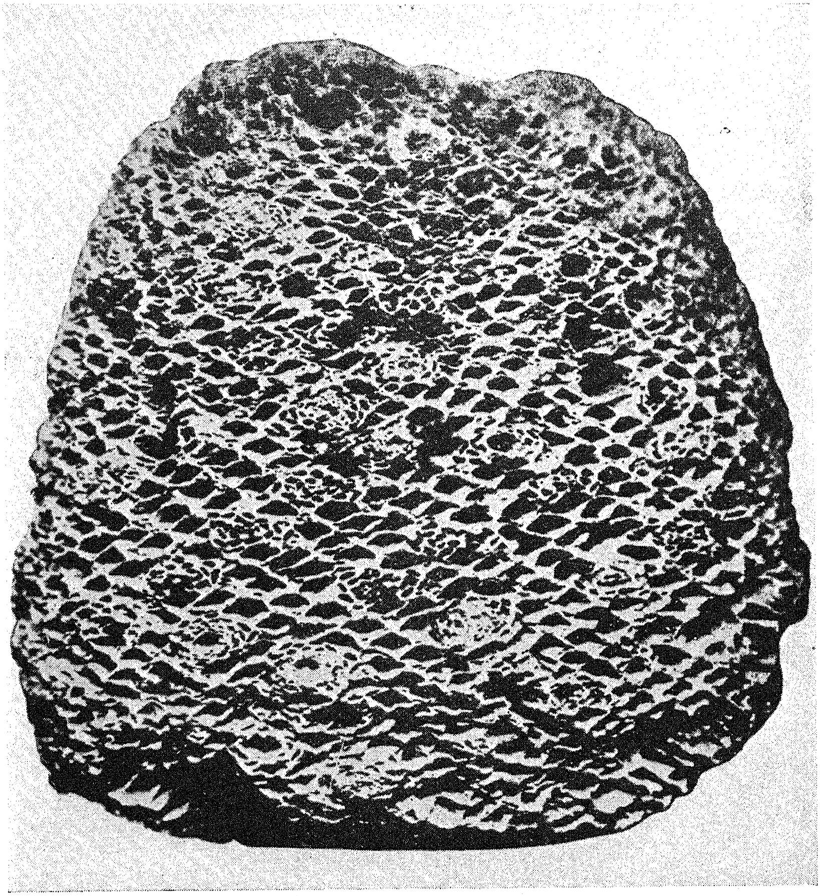


FIG. 69. Cycad trunk (*Cycadeoidea marylandica*) from the lower Cretaceous of Maryland. After Berry.

felted mass of thin, delicate scales not unlike the papery scales at the base of the leaf stalks in many living ferns. Curiously enough, this dense mass of scales has been preserved to the last cell, while the leaf bases themselves largely decayed and disappeared. By counting the rows of leaf bases on a trunk, which, however, is not always easy to do, some idea of the age of the trunk may be gained, which shows that they were often at least forty to sixty years old.

If we look again at *Figure* 69 we see a number of bud-like

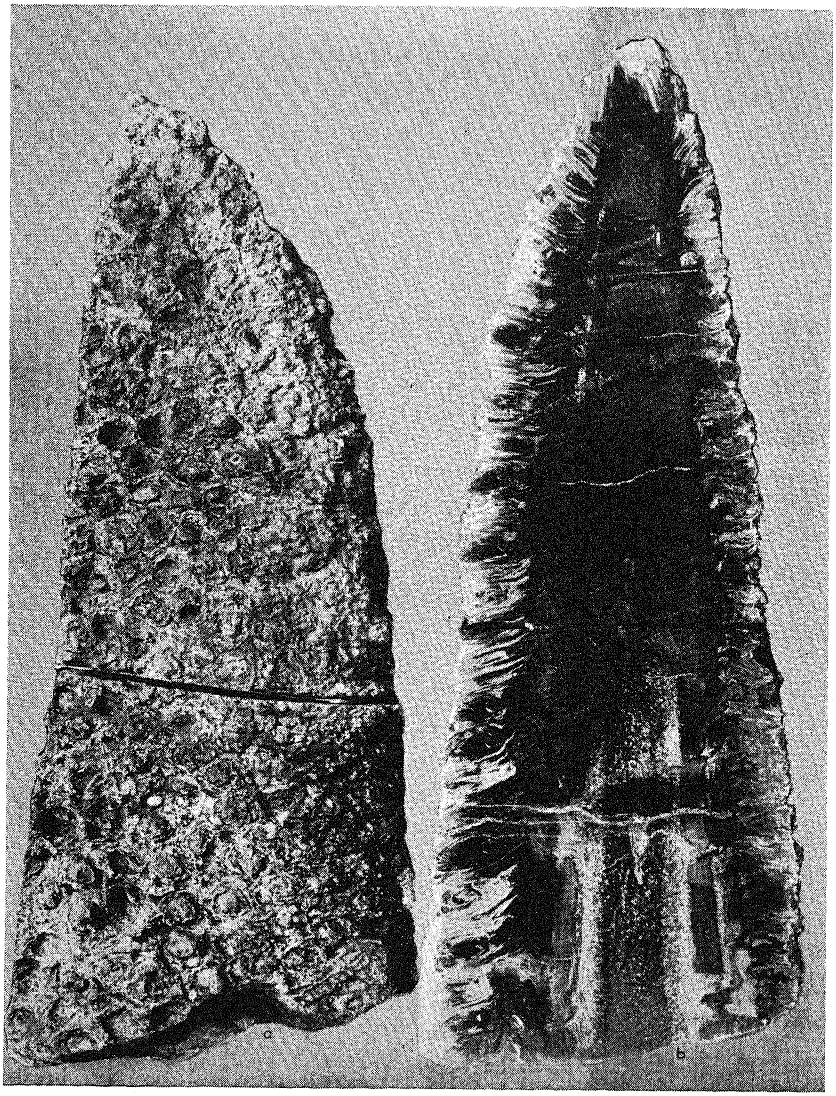


FIG. 70. Trunk of fruiting cycad (*Cycadeoidea dartoni*) from the Cretaceous of South Dakota. *a.* Outer view of trunk; *b.* longitudinal section showing pith, wood elements, and numerous fruits. Photograph from Dr. Wieland.

rosettes of what seem to be smaller leaf bases scattered over the trunk. These are the fruits, and their position along the sides of the trunk separate these from the living cycads, in which the fructification is always at the top of the trunk. The tips project very little beyond the leaf bases and their matted scales and look from the outside like small leaf buds rather than anything else: in fact, it is only by getting inside that their nature is disclosed. Now, if we cut a trunk lengthwise so as to cut through as many of these fruit rosettes as possible, we can find out the secret. This

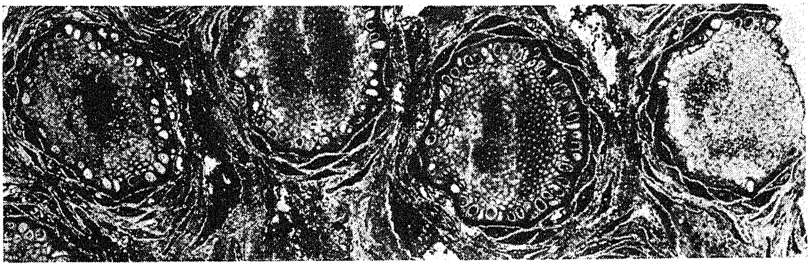


FIG. 71. Section through several ripe fruits of the cycad (*Cycadeoidea dartoni*) showing leaves, bracts, and seeds. Photograph from Dr. Wieland.

has been done in the trunk shown in *Figure* 70, which is a wonderfully preserved specimen from South Dakota, known as *Cycadeoidea dartoni*. In the center of the trunk is a very large pith, outside of which is a rather thin shell of wood with strands of tissue passing out to the leaves and other organs.

The fruit, shown enlarged in *Figures* 71, 72, has a short, rather stout body called a peduncle, which is enlarged at the top and bears numbers of slender organs, called pedicels, each bearing a single seed which ends in a bottle-shaped tip. Scattered among the pedicels are many slender, hair-like organs (sterile filaments) which enlarge at the top into a somewhat shield-shaped body, and these, pressing against each other, completely enclose the seeds except where the bottle-shaped necks of the latter open outside. The pollen was produced in great abundance by curiously shaped stamens, which more or less surrounded the seeds, and although it is not positively known, it is thought that each fruit was self-pollinated, that is by its own pollen, and not from different plants as in the recent cycads, in which the two sexes are on separate

plants. But whatever the method of pollination, it was clearly very successful, for it has been stated that every one of the perfect seeds found has the embryo plantlet already formed in it.

The splendid specimen we are describing, *Figure* 70, was probably about three feet high when perfect (the base is lacking), and shows over five hundred fruits, and this leads to the interest-

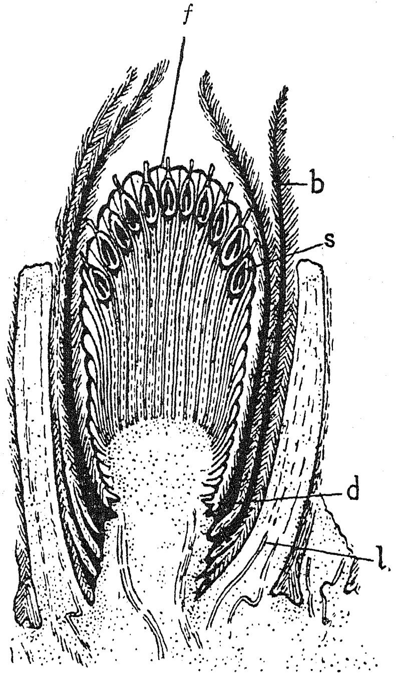


FIG. 72. Diagrammatic longitudinal section of ripe fruit of a cycad (*Cycadeoidea wielandi*). *l.* Old leaf bases; *d.* whorl of stamens; *b.* hair-covered bract; *s.* erect seed on slender pedicel; *f.* sterile filaments. After Wieland.

ing conclusion that possibly these cycads fruited only once. That is, after growing for perhaps half a century, a sudden impulse turned all the force of the plant into the production of seed, and when this had been accomplished the plant died. This habit is not uncommon in many living plants, but whether this is true of all the *Bennettitaceae*, or indeed of any of them, is not and cannot be positively settled.

At a locality known as the Freezeout Hills, in Wyoming, a large number of small cycad trunks were found, to which the name

Cycadella has been given. They probably belong properly with those first described, and although they have not yet been fully studied, it is not presumed that they will show much if anything not already brought out. They are usually only about twelve inches high, and show little evidence of branching.

With this digression we may return to the Patuxent flora, taking up first the conifers.

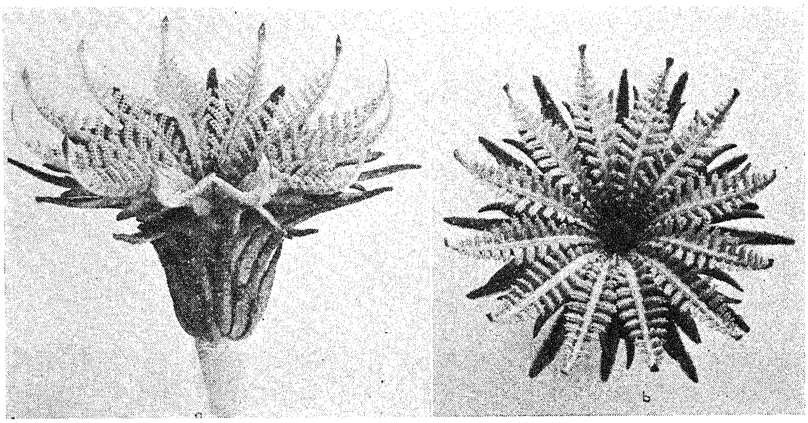


FIG. 73. Glass model of flower of cycad (*Cycadeoidea*). *a*. Side view, showing flower stalk, enveloping bracts, and large compound "stamens"; *b*. top view, showing "stamens" and pear-shaped female organ in center. Photographs by Dr. Wieland.

The conifers were undoubtedly the largest and most conspicuous plants of Patuxent time, and they probably made pure stands in many cases. Thus there were no less than five supposedly distinct kinds of *Sequoia*, most of them being nearest to the giant sequoia of California rather than the redwood. There was a small cypress (*Taxodium*), that was probably the forerunner of the bald cypress, that came to be so abundant and widespread during Tertiary time, and, but slightly modified, is still living in our southern swamps. The group of trees which includes the oriental cypress (*Cupressus*) was represented by several trees known as *Cupressinoxylon*. These are based on petrified trunks, some of which were two feet or more in diameter but of unknown height. Some of the foliage described under other names doubtless belongs to these trunks but has not been joined to them. *Araucaria*, the so-called monkey-puzzle or Norfolk Island pine, no longer native

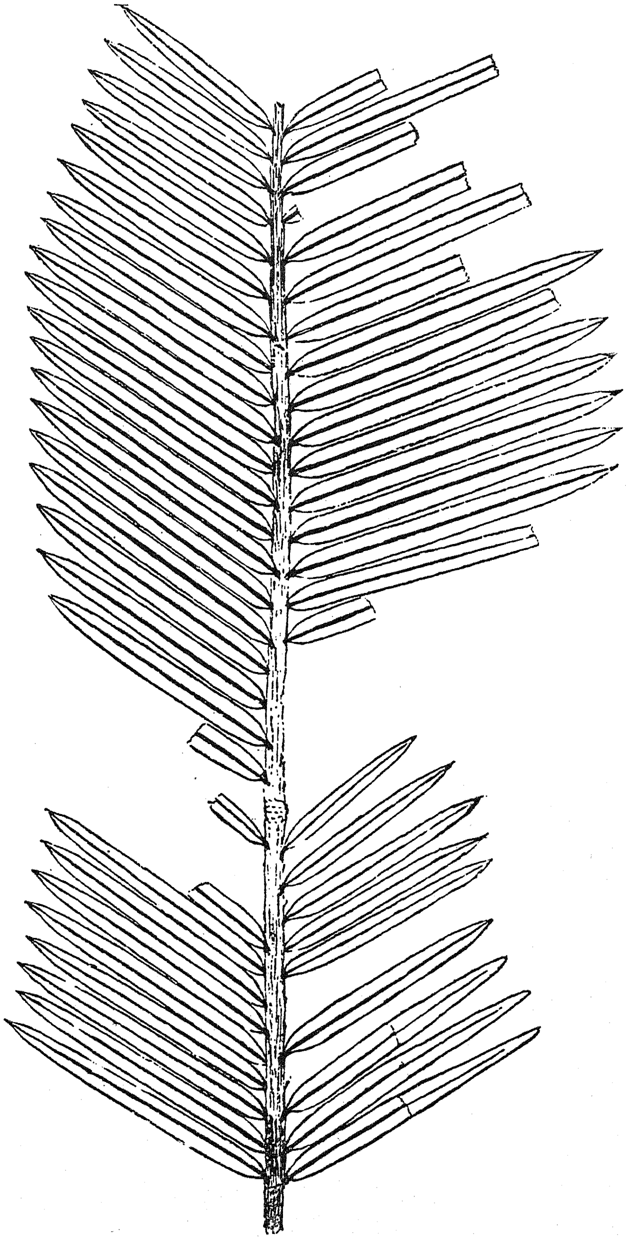


FIG. 74. Leafy branch of yew-like tree (*Cephalotaxopsis magnifolia*) from Patuxent beds of Virginia. Slightly reduced. After Fontaine.

in North America, was represented by two or three well marked species. They had stiff, ovate, sharp-pointed leaves. The yew family was well represented by two kinds of stinking cedar (*Tumion*), and three of *Cephalotaxiopsis*. *Tumion* has four living species, one in Florida, one in California, called the California nutmeg, and two in China and Japan. The Patuxent trees seem to be nearest to the California species. *Cephalotaxopsis* is presumed to be the ancestor of *Cephalotaxus*, the oriental yew, of which there are four living kinds, now found only in China and Japan. They must have been handsome trees having a flat yew-like spray of leaves, some of them nearly two inches long (see *Figure* 74). Of quite different appearance was *Brachyphyllum* (*Figure* 75), which belongs to a group now wholly extinct. It somewhat resembles some of the junipers, but had short, very thick branches, closely covered with thick scale-like leaves. The maidenhair tree or ginkgo has not been found in these beds, but a close relative, called *Baiera* (*Figure* 65) was present. It had

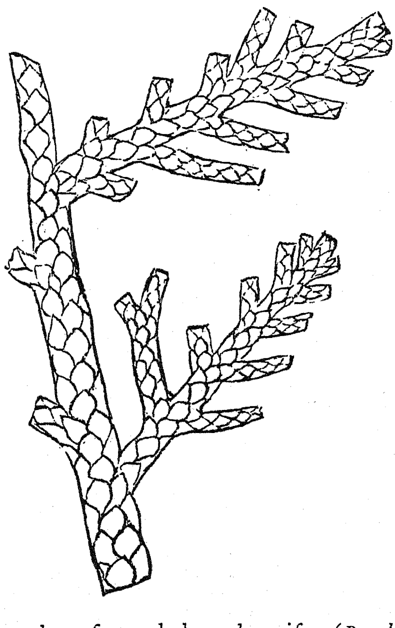


FIG. 75. Stem and branches of a scale-leaved conifer (*Brachyphyllum crassicaule*) from Patuxent beds of Virginia. After Fontaine.

leaves shaped like those of the ginkgo but deeply cut into several narrow segments.

We have now to consider some leaves that are in many respects more interesting and perhaps more significant than any others

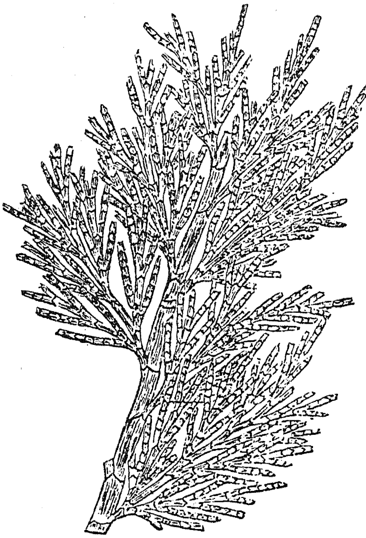


FIG. 76. Spray of a cedar-like conifer (*Frenelopsis ramosissima*) from Patuxent beds of Virginia. After Fontaine.

known from the entire Patuxent flora, namely, certain leaves which appear to have been those of angiosperms, or flowering plants—that is, plants in which the seeds are produced in a closed vessel or capsule, such as characterize the majority of living plants (see page 23). They are known as *Ficophyllum*, *Proteaephyllum*, *Quercophyllum*, *Rogersia*, etc. (*Figure* 77). They are rather crude-looking leaves, evidently thick and possibly leathery in texture, with a peculiar netted nervation. To all intents and purposes they seem to be the leaves of angiosperms, and if they had been found in beds in which such leaves might normally be expected, their angiospermous character probably would not have been questioned, but considering the fact that, if admitted to full standing, they would be among the oldest known representatives of this group, they have been very closely scrutinized. It is to be

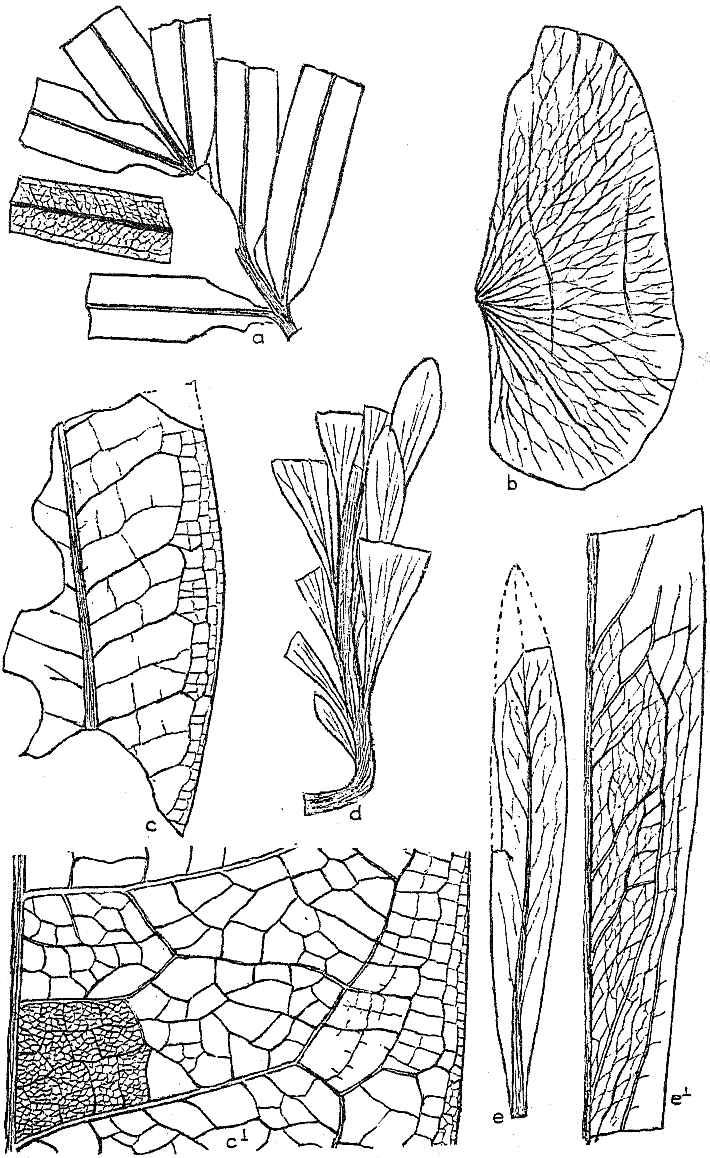


FIG. 77. Leaves of early supposed flowering plants from Cretaceous of Maryland and Virginia. *a*. Soapberry-like tree (*Sapindopsis variabilis*); *b*. proteaceous tree (*Proteaefolium rheniforme*); *c*. fig-like leaf (*Ficus? virginensis*); c^1. fragment of same enlarged 3 times to show nervation; *d*. acacia-like tree (*Acaciaephyllum spatulatum*); *e*. unknown leaf (*Rogersia augustifolia*); e^1. same enlarged 3 times. After Fontaine.

admitted that they are not what might be called normal and unmistakable angiosperm leaves, but this crudity could be expected among the earliest members of the group, and before they were fully established. However, they have been brought into question. By some students it is suggested that they are not angiosperms at all, but are the leaves of ferns, or possibly they may belong to the joint-firs (*Gnetales*), a peculiar group of conifers which have large, flat, angiosperm-like leaves. Unfortunately the controversy cannot be definitely settled one way or another at the present time, though it seems that they resemble the angiosperms more closely than they do any other known group of plants.

The time during which these Patuxent plants lived in Maryland and Virginia must have been of considerable length, long enough, in fact, for many of the species to spread for thousands of miles. This, of course, is on the assumption that this flora actually originated in this region, but, as we shall see later, many of the facts of distribution are more easily explainable if it is assumed that they began in the Arctic regions and spread southward. But, unfortunately, it is not known just where this flora originated, and so we must take the present knowledge of their location as we find it.

For instance, in the Rocky Mountain region there is a very thick series of beds that contain a flora of about eighty species, known as the Kootenai flora, which takes its name from that of the Indian tribe that once lived in the region. This flora includes thirty-four ferns, nineteen cycads, and twenty-five conifers, and must have been much the same in general appearance as the Patuxent flora; in fact there are at least fifteen species common to the two, and a number of others that are so closely related as to be separated only with difficulty. Much of this material is rather fragmentary, and as a consequence many, especially among the ferns, are not yet very well known. As usual, the conifers must have been the most conspicuous plants in this flora, and there are a number of very interesting things, among them a couple of pines, a spruce, a bald cypress (*Taxodium*), no less than half a dozen sequoias, and three supposedly different kinds of ginkgo, though these may be only variations of the leaves of a single tree. None of the supposed angiosperms have been found.

Still further west, in central California, is the Knoxville flora.

It is a very small flora of thirty-six species, which includes a horsetail (*Equisetum*), fourteen ferns, fourteen cycads, and only four conifers. Of these, fifteen, or nearly half, are the same as Patuxent species. Two kinds of supposed angiosperms have been described from the Knoxville, but they are very fragmentary, and of little importance.

There are a number of other, mostly small floras of the same age as those just mentioned, found in Texas, Wyoming, Queen Charlotte Islands, British Columbia, Greenland, and Spitzbergen. This brings us to the Old World, where we may first consider the plants of the so-called Wealden of England, which is the oldest of the Lower Cretaceous floras known from Europe.

The Wealden flora is a fairly rich one, including seventy-five species, which are about equally divided between ferns, cycads, and conifers. Perhaps the most interesting feature is the discovery that a full dozen of the Wealden plants were identical with those living in Maryland and Virginia, three thousand miles away, and also that nearly half of the genera were common to the two regions, though many of the species are slightly different. This indicates that these floras, now so widely separated, must have had a common point of origin, presumably in the north.

The Wealden flora includes a number of petrified cycad trunks very similar to those already mentioned as occurring so abundantly in America (see page 147); in fact, the first knowledge of the internal structure of these wonderfully preserved trunks came from the study of an English specimen. There are also a number of other cycads, based on the leaves, some of which are closely related to kinds that lived in Jurassic time. Among the conifers mention may be made of three or four kinds of pine known from petrified trunks, a cedar-like tree (*Thuites*), and two species of *Brachyphyllum*, that curious tree with the short thick branches closely covered with the close, scale-like leaves, but ginkgo has not been found, nor have any of the supposed angiosperms.

A number of plant-bearing deposits, believed to be of approximately the same age as the Wealden, have been found in western Europe, including especially Belgium, and several localities in Germany. There are a number of plants found at these places that are identical with, or closely related to, those of the Wealden of

England, as well as others of more or less interest. For instance, the beds near Quedlenburg in Saxony are remarkable for the numbers of supposed ferns of the extinct genus *Hausmannia.* These ferns—if they are ferns—have the leaves cut into a number of long, narrow segments not greatly unlike the leaves of some angiospermous plants, and indeed they have sometimes been regarded as belonging with them.

To go further afield, there is at least one place in South Africa where there is an assemblage of plants that have several species in common with the Wealden, and far away in Japan there is a small flora of only twenty-eight species, five of which are identical with those from the Potomac of Maryland and Virginia, thus showing that these early Cretaceous floras were practically worldwide in their distribution.

We have now come to the point, that is, in the later part of Lower Cretaceous time, that marks what was in many respects the most important step taken by plants in their whole developmental history, namely, the coming in of unquestionable angiosperms, or flowering plants. It will be recalled that, up to the present point, the story of the plants of the past has been concerned almost entirely with accounts of the ferns, horsetails, lycopods, and their kin, as well as with the many strange and unusual cycads and conifers. Some of these, including whole groups, had reached their climax and had disappeared, while many of the others had dwindled in size, number, and importance to the minor place they now hold in the plant world.

It is perhaps desirable at this point to give a brief description of the essential features of this great new group that was destined to sweep over the world in such an astonishingly short space of time. An angiosperm, then, is a seed-bearing plant in which the seeds are produced in a closed receptacle called a capsule or ovary. This serves to distinguish them from the other group of seed plants, such as the conifers and cycads, in which the ovules or seeds are without a closed covering. Of course the production of seeds was not new, for, as we have seen, as early as Devonian time, certain fern-like plants had already hit upon the seed-bearing plan, but they lacked the advantage of the true seed plants, which when mature have a tiny plantlet or embryo already developed in the seed, with a supply of food sufficient to

keep it going until it is established in the soil, and becomes, so to speak, self-supporting. But the production of true seeds in a closed vessel or capsule, with all that goes with it, was apparently the magic touch needed to start them on their conquest of the world.

Although it is not quite correct, as noted above, the angiosperms are often popularly spoken of simply as the seed plants or flowering plants. They are divided rather sharply into two groups, the monocotyledons and the dicotyledons. In the first group, which includes such plants as grasses, sedges, palms, lilies and the like, the embryo or plantlet in the seed has only one "first leaf" or cotyledon. In addition to this character, the stems show no distinction into pith, wood, or bark, and the leaves are mostly parallel-veined. The dicotyledons, on the other hand, have two cotyledons or seed leaves in the embryo, the stems show the divisions into pith, wood, and bark, while the leaves are mostly net-veined—that is, the veins are more or less joined to produce a network. This includes the oaks, elms, maples, roses, and thousands of familiar trees, shrubs and herbaceous plants on every hand.

This great group of the angiosperms seems to have sprung suddenly into existence, full-fledged as it were, in the middle and upper portions of the Lower Cretaceous. They are so characteristic and modern in appearance that there is not the slightest question about the correctness of their reference to this group, and, moreover, most of them can be referred with practical certainty to living families, and many of them to living genera. Their sudden advent in such mature forms, naturally suggests that they must have had a long time of preparation before our knowledge of them begins, but just where it was, or when it was, we are in almost complete ignorance, though faint glimmerings of possible light have come from time to time.[1]

[1] Some of the evidence bearing on the possible starting point for the angiosperms may be briefly summarized as follows: About 1894 Count Saporta, a distinguished French paleobotanist, announced the discovery in very early Cretaceous rocks of Portugal of certain leaves which he called Proangiosperms. At least one of these was later proved to be a fern, and the others are so fragmentary that their evidence has not been accepted as conclusive. Undoubted angiosperms are found in supposed lowest Cretaceous beds in Greenland, but the age of the beds is questioned. Some years ago Prof. A. C. Seward described and figured a small ovate leaf from the Middle Jurassic rocks of Stonesfield, England, that has every appearance of being a dicotyledonous leaf. If it had been found in beds that might reasonably be expected to contain such leaves there would probably be little hesitation in calling it a dicoty-

The second or middle one of the three plant-bearing divisions of the Lower Cretaceous in the Maryland-Virginia area is called the Arundel formation, so named from the county in Maryland where it is best exposed. The known Arundel flora is a small one of only about thirty species, mainly ferns and conifers, but including also five or six of the same angiosperm-like leaves (*Ficophyllum*, *Rogersia*, *Quercophyllum*, etc.) mentioned in the description of the Patuxent flora (see page 156). Although they are, in some respects, rather crude-looking leaves, they certainly seem most like the leaves of flowering plants, and it will probably ultimately be decided that they are really among the early forerunners of this great group.

The third or uppermost of the plant-bearing beds of the Lower Cretaceous in this region, known as the Patapsco formation, contains the remains of about one hundred species of plants, of which more than one-fourth belong to this newly evolved group of angiosperms, which was so soon to dominate the plant world. These are not only the oldest unquestioned plants of this group known in North America, but they have been found to be as old as, if not older than, any similar plants found elsewhere in the world. They are so plainly and unmistakably the leaves of highly developed types of flowering plants that no question can be raised as to their position. In fact, if a student of present-day trees and shrubs could have wandered over the hills and vales of Maryland and Virginia in Patapsco time, he would have found himself

ledon. Considering the uncertainty, however, Seward contented himself with naming it *Phyllites*, which means simply a plant of undetermined affinity. In slightly older Jurassic beds from Yorkshire, England, Prof. H. H. Thomas has recently found a number of fruits arranged in two rows on a stalk, each fruit containing a number of minute seeds. He also found in association, though not attached, branched stamens with four-lobed anthers and compound palmate leaves (*Sagenopteris*), all of which may have belonged together. The possession of seeds in a closed capsule, as well as the associated organs, seem to fill the requirements of veritable angiosperms, and they should probably be so accepted, although their kinship with living forms has not been recognized. Still more astonishing is the recently reported claim made by Dr. A. C. Noé, of the University of Chicago, of wood apparently showing angiospermous structure in coal balls from the Carboniferous fields of southern Illinois. Probably the most convincing evidence of the presence of highly organized dicotyledonous trees in the lower part of the Cretaceous has recently been supplied by Dr. Marie Stopes. These woods are found in southern England in the so-called Lower Greensand, next above the Wealden formation, which is the lowest formation in the Cretaceous of the region. Although their affinity with recent trees has not been recognized, they were by no means primitive in structure.

quite at home among the trees and shrubs growing there. He would have recognized with reasonable certainty most of the families represented, and in many cases could have placed the plants in or near living genera, so little have they changed in coming down to the present. No less than sixteen modern families of flowering plants (angiosperms) are represented in the Patapsco flora, many of which are only remotely related among themselves, and some of the genera embrace four or five species, all of which seems to show conclusively that the group must have been developed somewhere for a very long time.

Among the more conspicuous families in the Patapsco flora, mention may be made of the willow family (*Salicaceae*), which is represented by two kinds of poplar, and three poplar-like trees, the beech family (*Fagaceae*), with a single oak-like tree that may be near the starting point of the vast group of oaks that are now so widely spread over the world; the elm family (*Ulmaceae*), with three kinds of elm-like plants; the mulberry or fig family (*Moraceae*) with a species of fig; the ginseng family (*Araliaceae*), with three species of aralia-like trees; the staff tree family (*Celastraceae*), represented by six different kinds of what were probably climbing shrubs closely related to the common bittersweet; the grape family (*Vitaceae*), with two genera, one (*Cissites*) related to the well known Virginia creeper, and the other (*Hederaephyllum*) to the so-called English ivy; the laurel family (*Lauraceae*) represented by three species of sassafras, the only living representative of which is a native of eastern North America; the soapberry family (*Sapindaceae*), with three kinds of soapberry (*Sapindopsis*), evidently one of the most abundant types of this flora; and finally the water-lily family (*Nymphaeceae*), with two kinds of lotus-like aquatic plants having small floating leaves.

It has been assumed by many that this new angiospermous type of vegetation actually originated in eastern North America, where it first certainly came to be known, but there are certain facts of distribution that make it seem probable that it came into existence in the north, and later migrated southward. Thus, in Portugal, in beds of approximately the same age as the Maryland-Virginia beds, a well-marked group of flowering plants has been found, some of the species of which are identical or closely related to

those of the Patapsco. This flora includes two willows, an oak-like leaf, a sassafras near to the one of the Patapsco species, a magnolia, two aralias, an *Aristolochia*, two kinds of *Cissites* of the grape family, one being the same as Patapsco species, and two members of the water-lily family. Besides these flowering plants there is a considerable number of ferns, cycads, and conifers, but they have not yet been fully studied.

From the Black Hills region, in South Dakota, there is another small flora (Fuson), of about the same age as the Patapsco, that includes some five or six species of flowering plants, among them one (*Sapindopsis*) identical with one of the commonest of the Virginia forms. The others are fragmentary and not well known. The most striking plants in the Fuson flora are the huge petrified cycad trunks already mentioned.

This closes the account of the plant life of Lower Cretaceous time, the outstanding feature of which is the coming of the flowering plants.

After the close of the Lower Cretaceous, and a time interval that varied in length in different parts of the world, we come to the Upper Cretaceous. Whether long or short, this time interval was sufficiently long to have permitted the newly evolved group of angiosperms to spread widely over the earth almost overnight, one might say, as geologic time is reckoned, and to assume the commanding positions they now occupy. The ferns, cycads and conifers, long the dominant types, were crowded more or less into the background, and the earth had become in effect a world of flowering plants.

Plant-bearing beds of Upper Cretaceous age are known from many parts of the world, and as these beds are often highly fossiliferous, as shown by the fact that several thousand species of plants have been found, it follows that our knowledge of the plant life of the time is fairly complete, though doubtless far short of the whole story. These floras are so large and varied that it will be impossible in the space available to give more than a cursory glance at the more important deposits and the more interesting or striking plants.

We may appropriately begin the review of Upper Cretaceous floras with what is called the Raritan flora. (See *Figure* 78.) The beds in which this flora is preserved are composed largely of clays

and sands, and extend from Martha's Vineyard, Massachusetts, to the Potomac River, being best developed in New Jersey. The Raritan flora comprises nearly three hundred species, of which more than two hundred were flowering plants. The subordinate position of the ferns and cycads is emphasized by the fact that, combined, there are less than twenty species. The conifers had a much better showing, with over fifty species, indicating that the mixed forests of conifers and hardwoods had already developed, though our knowledge of some of the conifers is still limited, and many of them were destined to die out before Tertiary time.

Of course many new types of flowering plants, all trees or shrubs, made their appearance, some of them, indeed, being more numerously represented than they are at the present time. For instance the tulip-tree (*Liriodendron*), now represented by a single or possibly two species, had three large-leaved kinds and three more supposed primitive relatives, called *Liriodendropsis*. *Sassafras*, with a single living species, had four or five, and magnolia had no less than nine species, or more than now live in North America. The persimmons (*Diospyros*) first appeared with half a dozen species, the bayberries (*Myrica*) with nine species, and the maples (*Acer*) with two well-marked forms. The aralias, doubtfully represented in the Patapsco flora, had ten species and four near relatives (*Araliopsis*) in the Raritan flora, and *Eucalyptus*, now native only in Australia, was represented by seven species.

After a considerable time interval there was developed, in practically the same region as that occupied by the Raritan, another series of plant-bearing beds known as the Magothy formation. The Magothy flora numbers over three hundred and twenty-five species, considerably more than two hundred of which were flowering plants. Some forty species of Raritan plants had lived on into the Magothy, and besides a number of new introductions, many of the earlier types had still further expanded. Thus the tulip-trees and their relatives numbered eight species; the magnolias were represented by fourteen species; the sassafras by four, the figs (*Ficus*) by no less than thirteen, the aralias by ten, and the oaks by half a dozen species. The monocotyledons, although extremely rare and poorly preserved, were coming into the picture, and included grasses, sedges, cat-tails (*Typha*), and palms. Coni-

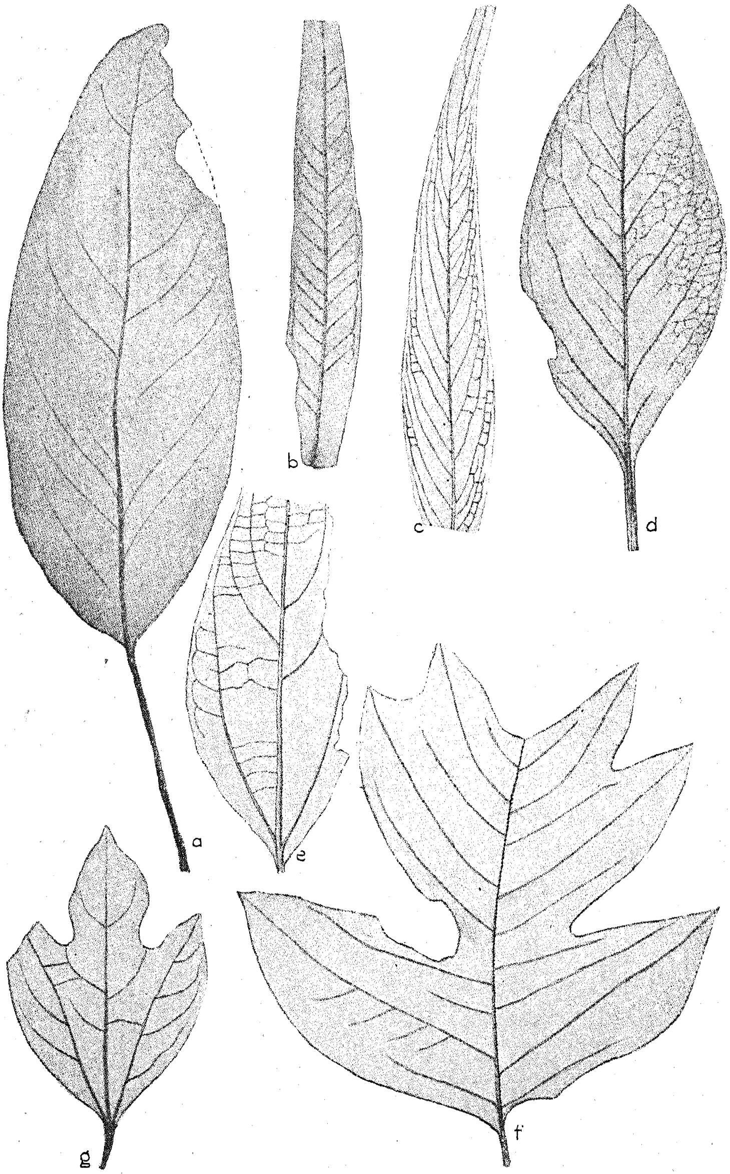


FIG. 78. Leaves of trees from the Upper Cretaceous Raritan flora. *a.* Magnolia (*Magnolia woodbridgensis*); *b.* eucalyptus (*Eucalyptus geinitzi*); *c.* willow (*Salix marginalis*); *d.* persimmon (*Diospyros primaeva*); *e.* camphor tree (*Cinnamomum newberryi*); *f.* tulip tree (*Liriodendron quercifolium*); *g.* sassafras tree (*Sassafras progenitor*. After Newberry.

fers held about the same proportion as in the Raritan, showing that the forests were conspicuously of the mixed type.

Plant-bearing beds of approximately the same age as those just mentioned are found along the Atlantic Coastal Plain from North Carolina to Texas and add many more to the long list of Upper Cretaceous plants.

Lending further support to the supposition that those floras may have originated in the north and spread southward in successive waves, mention may be made of large Upper Cretaceous floras found in Greenland. These floras, known respectively as the Atane (oldest) and Patoot floras, combined include about three hundred species, though there is some duplication, as a number of species occur in both series. Many of these Greenland plants spread as far south as Texas, there being, for example, forty-seven in the Raritan, thirty-seven in the Magothy, and thirty-six in the Dakota flora, with smaller numbers in the several Coastal Plain beds.

The Greenland floras show much the same mixture of conifers and hardwoods as already mentioned, including sequoias, junipers, cypress, pines, and ginkgos, with maples, oaks, dogwoods, walnuts, persimmons, figs, tulip-trees, laurels, cinnamon trees, eucalyptus, and sycamores. Ferns, some of them evidently tree-ferns, were more abundant and varied than in the eastern United States.

Perhaps the most interesting member of the Greenland flora is an undoubted breadfruit tree (*Artocarpus*), which is represented by both leaves and fruits. As the breadfruit is found living at the present day only within twenty degrees of the equator, its presence so far north in Greenland in Upper Cretaceous time suggests a similar climate, provided, of course, its requirements then were similar to those at present demanded. Interpretations differ as to the probable climate of Greenland during Upper Cretaceous time, though seemingly it could hardly have been cooler than very warm temperate.

Turning from Greenland and the Atlantic Coastal Plain to the interior of the continent, we have a very large flora, known as the flora of the Dakota sandstone, with over five hundred species. (See *Figure* 79.) This splendid flora lived on the lands bordering the great inland sea, which has already been mentioned as bisect-

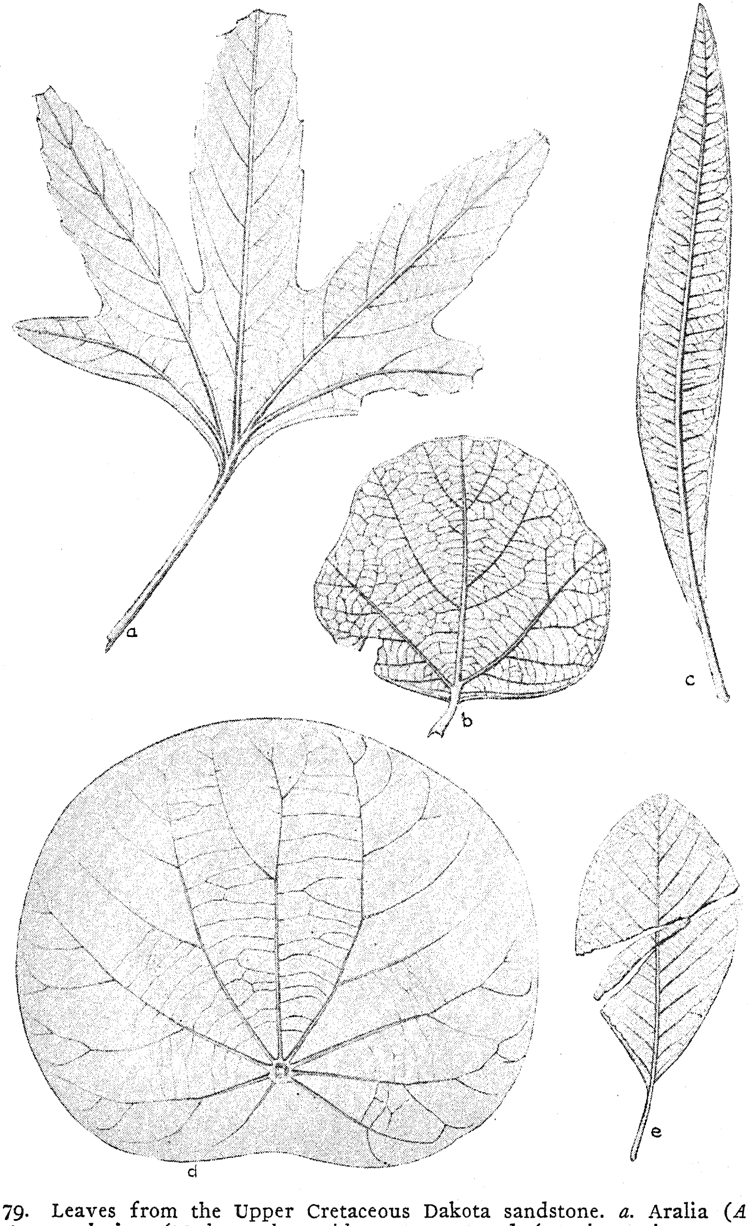


FIG. 79. Leaves from the Upper Cretaceous Dakota sandstone. *a.* Aralia (*Aralia saportanea*; *b.* ivy (*Hedera platanoides*; *c.* moonseed (*Menispermites grandis*); *d.* beechnut (*Fagus cretacea*). After Lesquereux.

ing the continent at this time. Beds containing this flora are known from Texas to British Columbia and Alaska, the richest beds being in Kansas, Nebraska, Iowa and Minnesota, and it even spread five thousand miles to the south, to central Argentina.

The Dakota flora was made up almost entirely of flowering plants, in fact there were only about seven species of ferns, ten cycads, and fifteen conifers, and as some of these are very fragmentary and imperfectly known, it is evident that they were not very conspicuous. All the conditions of growth seem to have been very favorable, with the result that many of the plant types were evidently undergoing rapid development, and were splitting up into different forms, many of which were later to spread widely over the world. For example, the tulip-trees were represented in Dakota time by eleven species, some of which had much larger and more strongly lobed leaves than the living species. There were eight willows, eighteen poplars and poplar-like trees, twenty oaks, twelve species of sassafras as compared to the single living species, ten magnolias, seven hollies (*Ilex*), twenty-three kinds of figs (*Ficus*), six or seven persimmons, more than a dozen aralias, some with very large handsome lobed leaves, ten or more laurels (*Laurus*), as well as many genera of trees or shrubs now extinct or found only in the Old World.

Many of the trees that were so important during Dakota time, either did not survive after its close, or were reduced in numbers and were modified and migrated to other parts of the world. In the interior of the continent, mainly within the region now covered by the Rocky Mountains, there were numerous other smaller floras that followed the Dakota, showing that the flowering plants were undergoing rapid change and distribution, but, interesting as they are, lack of space prevents their consideration at this time.

Remains of plants that lived in Upper Cretaceous time are known in many parts of the Old World, but nowhere are they so abundant, or so thoroughly studied as in North America. Some of those that lived in Greenland migrated southward into western Europe, and many of the Old World genera were the same as those that lived in North America, but for the most part the species were different. There were evidently the same mixed forests of conifers and hardwoods, though the proportion of

conifers seems to have been larger, but possibly this is because the conifers are easier to recognize, and the flowering plants have been less thoroughly studied. Small floras are known from France, Spain, Portugal, and Germany, with still smaller numbers in Russia, Japan, Australia and New Zealand.

Chapter XI

THE PLANTS OF EOCENE TIME

THE Mesozoic era, or the so-called time of middle life, came to its close with the end of the Cretaceous period, and we enter the Cenozoic era, or time of new or modern life. Although this era probably covered less than five per cent of the whole of geologic time, it was, as we shall see, a time of vast importance in its effect on the origin, character, and distribution of the plant life of the present day. The Cenozoic era is divided into two periods, the Tertiary and the Quaternary. The Tertiary period, the older of the two, comprises three approximately equal divisions, namely, the Eocene,[1] the Miocene, and the Pliocene.

As we have seen in the last chapter, the angiosperms, or flowering plants, had come to be the dominant class of plants by the close of the Cretaceous, and many of the modern families and genera, including especially the so-called hardwoods, had been established and widely spread over the world. These continued into and through the Cenozoic, with here and there a genus dropping out, and other genera arising, to establish the present-day flora. Some types waxed mighty and then, for some unaccountable reason dwindled to a feeble representation among living plants, and others, with a modest beginning in late Cretaceous or early Tertiary time, have come to be among the most important of our everyday plants. To attempt to give anything like a complete account of the origin, change, and migration of these floras the world over, would take far more space than is allowable here, so, for the remainder of our story of the plants of the past, it is proposed to take up important regions and to show what plants lived in them at the different geologic stages, how they came to be there, where they went, and why they were driven out, and the

[1] In recent years an additional epoch known as the Oligocene is often introduced between Eocene and Miocene. These beds have usually been included in the Eocene but have been separated largely because of the distinctness of the two series in Europe, and they can be readily separated in North America wherever fossils occur. In the following account the beds usually placed in the Oligocene are included under the Eocene.

climatic and other conditions under which they lived—in fact we shall try to reconstruct the floral landscape as well as the available facts, and space, may permit.

We may appropriately begin with the wonderfully rich flora that lived in Greenland during Eocene time. We are accustomed to think of Greenland today as a land of intense cold, with a perpetual covering of ice and snow, and, indeed, there are thousands of square miles covered with vast thicknesses of ice, but around the southern and western sides, and even at the northern end, there is a broad strip of land that is ice-free in summer. Over four hundred species of flowering plants now live in Greenland, some of them extending as far north as 82°, or within eight degrees of the North Pole. These plants are for the most part what are called herbaceous perennials, that is plants with underground stems or rootstocks which send up each year the short herb-like stems that bear the flowers and perfect the seeds in the few short weeks of the Arctic summer. There are few real trees, though there are several tiny willows with stems only a few inches in height, yet sometimes showing as many as fifty growth rings in a stem hardly thicker than a pencil.

We may pause a moment to consider what are known as herbs. Herbs, then, are plants that do not possess a woody stem above ground, but are made up of softer tissues, and usually die down to the soil after flowering. They may be annual, when the entire life history, from the germination to the ripening of the seed is carried out in one year; biennial, when this process requires two years, after which the plant dies; or perennial, when the plant lives for several or many years, sending up each season from an underground woody stem the soft, non-woody stems that bear the flowers and perfect the seeds, when they die down at the approach of winter. It now seems to be very generally accepted that the herbs are descended from woody plants.

It is a matter of common knowledge that herbs did not appear, at least in force, until well into Tertiary time, and there has been a good deal of speculation as to how this condition came about. Recently Dr. E. W. Sinnott has advanced a very plausible explanation, writing as follows: "These facts—that woody plants are more ancient than herbs is shown by evidence from fossils, from natural relationships, and from anatomy; that herbs

are now dominant and woody plants few in species in regions subject to low temperatures, and vice versa; the regions which have been isolated from the north-temperate land-mass possess few herbs in the ancient portion of their floras, and that the northern continents supported at no very ancient day a much more varied woody vegetation than at present—all suggest the conclusion that a large part, at least, of our northern herbaceous vegetation originated in the north temperate zone in response to the progressive refrigeration of climate which we know to have taken place there during the Tertiary.

"The great advantages conferred by the possession of an herbaceous habit of growth in a region subject to low winter temperatures are obvious, for such plants are able to complete their cycles and to mature seed in the warm summer months and can survive the cold of winter in the form of resistant seeds or by hibernating underground. Only the hardier types can maintain permanent aerial stems under these conditions. The more delicate woody families have either been exterminated outright in temperate regions or have survived only by assuming an herbaceous habit and thus flourishing in that part of the year which is free from frost."

This habit of "digging in," so to speak, is well exemplified in the present flora of Greenland, where over ninety per cent of the flowering plants are herbs. The decrease of herbaceous types from arctic and alpine regions to the heart of the tropics is well shown by the following figures: Thus in Ellsmereland the percentage of herbs is 92, Switzerland 91, Iceland 90, Great Britain 89, Rocky Mountains 87, northern United States 78, Japan 57, tropical Africa 42, Ceylon 37, Java 27, Brazil 26, Lowlands of the Amazon Valley 12.

But let us return to the west coast of Greenland and try, in our mind's eye, to reconstruct the wonderful flora that lived there in this late Eocene time. In beds of shale some hundreds of feet in thickness, the remains or impressions of nearly three hundred different kinds of plants have been recovered, and we are impressed at once by the fact that all, or nearly all, seem to be very different in character and appearance from those now living in Greenland. We note the presence of several thin beds of coal, and a recently returned Arctic explorer reports the presence of thick

beds of lignite on Ellsmereland a short distance to the northwest. This shows that there was a quiet, long-continued swamp or marsh condition, for it is mainly in such a setting that coal is formed.

If we could have walked over the low hills, and along the streams and marshes, we might have seen many familiar plants—that is, familiar as regards the types, though quite different as regards the species. In the moist meadows there were grasses and sedges of several kinds, with clumps of chain ferns (*Woodwardia*), ostrich ferns (*Osmunda*), horsetails (*Equisetum*) and irises. There were patches of bracken (*Pteridium*), sensitive ferns (*Onoclea*), lady ferns (*Asplenium*), and, nearer the swamps, perhaps growing partly in the water, were tall grasses (*Phragmites*), whose descendants now help to make the so-called cane brakes of our southern swamps. On the surface of quiet pools were the floating leaves of pond weeds (*Potamogeton*), and about the edges were clusters of bur reed (*Sparganium*), and water plantain (*Alisma*). In the swamps were many tall trees of the bald cypress (*Taxodium*), so like those of the swamps of our southern states that we would hardly have been able to see any difference between them. There were also several kinds of true cedar (*Thuja*), and a small tree called the stinking cedar (*Tumion*), as well as sycamores (*Platanus*), swamp magnolias, and willows, with at least two kinds of cat briers (*Smilax*) clambering over the lower bushes as they do in our southern swamps today. Along the streams and in the moist lowlands were willows, alders, poplars, bayberries (*Myrica*), sweet gum (*Liquidambar*), black gum (*Nyssa*), elms, and tulip-trees (*Liriodendron*). On the lower hills were oaks, maples, birches, ashes, as well as hornbeams (*Carpinus*), hop-hornbeams (*Ostrya*), and hazelnuts (*Corylus*), with an occasional maidenhair tree (*Ginkgo*). On the rocky ledges were two kinds of juniper (*Juniperus*), and several kinds of sequoia, one of which had leaves and cones very like those of the redwood of the Pacific coast. In the rich uplands were many familiar trees and shrubs, such as beeches, dogwoods, sumacs, hollies, hickory nuts (*Hicoria*), walnuts (*Juglans*), persimmons of several kinds, buckthorns (*Rhamnus*), grape vines, sassafras, hawthorns (*Crataegus*), plums, and magnolias. Under the stately trees were little beech ferns (*Phegopteris*), shield ferns (*Dryo-*

pteris), ground pine (*Lycopodium*), mosses, and on old rotting logs the familiar bracket fungus (*Polyporites*).

This by no means exhausts the list of plants that grew in these wonderful Greenland forests so many hundreds of thousands of years ago, but it is enough to bring out clearly a number of interesting points. As already hinted, it is almost wholly different from the flora now living in Greenland, but, further than this, it is an assemblage of plants that could not possibly live there under present climatic conditions. It was what we would call today a temperate flora, while the present-day flora of Greenland is Arctic or sub-Arctic. It was a flora that would find a congenial home some twenty or twenty-five degrees further south, or in Maryland, Virginia, and the Carolinas.

It is obvious that the climate of Greenland has changed greatly since late Eocene time, and the question naturally arises as to what caused or permitted this change. Many explanations have been offered, but as yet none that seems to meet all the requirements.

At the same time this temperate Upper Eocene flora was living in Greenland, there was another almost totally different flora living in the southeastern and southern United States; in fact there is only one tree—the bald cypress—that is known to have been common to the two regions. But, curiously enough, there were quite a number of these Greenland species that lived in the southern United States in early Eocene time. This is thought to be explained by the fact, that, during the whole of Eocene time, the temperature in the southern states was rising, through some cause, and as the warm conditions extended farther and farther north, the temperate types were able to migrate northward. This doubtless took many thousands of years, and when cooler conditions came on, which foreshadowed the coming of the Ice Age, the southern advance of the cooler climates was slow enough to permit many of the plants to "escape" again to the south, some into western Europe and eastern Asia, and others into various parts of North America.

During the whole of Eocene time there was a very rich flora, of which over six hundred species have actually been recovered, that lived on the southern coastal plain, which extended from North Carolina to Texas. During this period the crust of the earth in

this region was relatively quiet—that is, there were no violent changes, such as occurred in the western interior and near the Pacific Coast—though there were many minor changes of level, which at times permitted the sea to spread farther over the land, once at least as far north as southern Illinois. It was a low, flat, sandy plain, with swamps, marshes, and innumerable ponds and bayous.

It has been found that three quite distinct floras occupied this Coastal Plain area successively during Eocene time. The first or oldest of these is known as the Wilcox flora, with over four hundred known species of plants. It included many strange trees and shrubs whose nearest of kin are now found mainly in Central America, northern South America, and the West Indies, with not a few that now live only in various parts of the Old World. It appears to indicate a very warm temperature, indeed, almost subtropical climate.

There were five or six kinds of small ferns, none very conspicuous, though among them was a handsome little climbing fern (*Lygodium*). Coniferous trees were apparently rare and local, there being only two species, the bald cypress (*Taxodium*) and a cedar-like tree (*Glyptostrobus*), whose nearest relatives now live in the river valleys of southeastern Asia. Curiously enough, no remains of grasses or sedges have been found, though they must have been present. There was one small cycad, not greatly unlike the coontie (*Zamia*) of the east coast of Florida. Palms, both fan-shaped and pinnate-leaved kinds, were present, with one (*Nipadites*) known only from the large fruits; its relatives now live in the Old World tropics. There were two or three species of canna, now so well known as ornamental and bedding plants. Walnuts, hickories, and bayberries were sparingly represented, and a near relative of the walnuts called *Engelhardtia*, having large, curious three-winged fruits; it now inhabits tropical America and the Old World tropics. There were no true oaks, but a near relative (*Dryophyllum*) with quite oak-like leaves, and supposed to be one of the ancestors of the oaks. The breadfruit tree (*Artocarpus*) is now found native only in the tropics of the Old World, yet during Wilcox time, there were two well-marked species in our southern states, one being hardly distinguishable from the well-known breadfruit grown in many tropical countries

the world over for its edible fruit. *Ficus*, the genus to which the fig belongs, is a vast group of more than six hundred living species, which are widely spread over both the Old and New Worlds, mainly within the tropics. Only two kinds are native in the United States, but in Wilcox time no less than sixteen species lived along the Coastal Plain, some of them with large and remarkably handsome leaves; their nearest of kin are found mainly in the American tropics. Another mainly tropical group of trees is comprised in the laurel family (*Lauraceae*), and has thick, handsome leaves. With these are included the cinnamons, swamp bays (*Persea*), and several related species. Taken in its broadest meaning, the pea family was one of the most abundantly represented in the Wilcox flora. It included several acacia trees, honey locusts, and redbud or Judas trees (*Cercis*). There was also the custard apple (*Anona*), the papaw (*Asimina*), the *Minusops*, and the soapberry (*Sapindus*), forms that are now mainly tropical, as well as many more familiar trees and shrubs, such as magnolias, dutchman's pipe (*Aristolochia*), bittersweet (*Celastrus*), spindle tree or burning bush (*Euonymous*), buckthorn (*Rhamnus*), black gum (*Nyssa*), and ash (*Fraxinus*).

There were many other interesting plants that lived in Wilcox time, but we must pass them by and turn to the Middle Eocene flora, which occupied the Coastal Plain region after the Wilcox flora had died out or had been driven out. This is called the Claiborne flora. It was not nearly so rich as the Wilcox flora, at least so far as is now known, including only about a hundred species. Many of the Wilcox genera lived on, but the species had nearly all changed, showing that there had been a considerable lapse of time. A number of interesting new plants came in, among them *Acrostichum*, a genus of large ferns, of which two species are recognized. The living forms are mostly swamp plants, one in particular being a common species of the mangrove and nipa swamps, in both the New and Old Worlds. Three or four conifers were present, but they must have been very local in their distribution. Among them was the *Glyptostrobus* already mentioned, and two based on petrified trunks, which were allied to the *Sequoia*. There were several palms, but they were so poorly preserved that they are very imperfectly understood, though it is known that one (*Geonomites*) had very large pinnate leaves. The

three kinds of figs present—one with large handsome oblong leaves—all have relatives in the American tropics. Mention should also be made of an interesting tree called *Citrophyllum*, which was very abundant in places, and which was undoubtedly one of the ancestors of the group to which the cultivated orange and lemon belong. These leaves are known by the fact that the blade separates from the winged petiole by a regular joint, showing that it is virtually a compound leaf, though having only one leaflet. *Citrus*, the genus to which the orange belongs, is confined at present to Indo-Malayan regions of the Orient. Quite a number of the Claiborne plants are known only from their seeds or fruits, and may have grown locally or perhaps were brought in by ocean currents, as it is known that some retain their vitality after a considerable immersion in salt water.

The time interval between the Claiborne and the overlying Jackson time was evidently shorter and less devastating than that separating Claiborne from Wilcox time, with the result that many of the plants were able to survive from the one to the other. The time during which the Jackson flora flourished was relatively long, covering the whole of the Upper Eocene, and, as might be supposed, there were considerable differences in the physical setting between its extremes of Georgia and Texas. It was essentially a low coastal plain, with lagoons, barrier beaches, and long, narrow estuaries and swamps, which supported a beach jungle, such as may now be seen along the coasts of tropical America.

The known Jackson flora is not a large one, less than a hundred and fifty species, but it includes a number of very interesting plants. Among them mention may be made of the fern *Acrostichum*, which survived from Claiborne time and evidently grew profusely in the swamps, as does its near living relative, which often forms a dense growth eight or ten feet high. There are numerous fragments of a tall, reed-like grass (*Arundo*), large floating leaves of a pond weed (*Potamogeton*), and a handsome smilax not unlike species now living in southeastern North America. Three coniferous trees were present, the bald cypress and the *Glyptostrobus* already mentioned, and the cones of a supposed cypress (*Cupressites*), but they were evidently very rare, and altogether inconspicuous. Palms were apparently abundant, some eight or nine forms being recognized, but most of them are so

poorly preserved that they cannot be fully characterized. The most remarkable was an undoubted date palm (*Phoenicites*) that lived in central Texas. The living date palms, to the number of about a dozen species, are all native of northern Africa and eastern Asia, but this Jackson species proves that it was once a native of the New World.

Another interesting and important Jackson plant was the mangrove (*Rhizophora*), which was especially abundant on the coast of Georgia. The mangrove, three living species of which are recognized, is one of the few flowering plants especially adapted to live in salt water. It forms at the present day a tangled mass of stems and roots along tidal flats and inlets of the tropics the world over, and serves to arrest and hold the mud and silt swept back and forth by the tides, thus helping to build up the land, as it apparently did in Eocene time.

Back of the mangrove and acrostichum swamps was the so-called beach jungle, made up of figs, soapberries (*Sapindus*), many trees and shrubs of the pea family, a small tree with magnolia-like leaves known as *Terminalia*, etc., all strikingly similar in habit and appearance to the flora now found in similar situations throughout the tropics of both Old and New Worlds. In addition there were some more familiar forms, such as the bayberry, chestnut, water elm (*Planera*), cinnamon tree, laurels of several kinds, custard apple (*Anona*), basswood (*Tilia*), buckthorn (*Rhamnus*), redroot (*Ceanothus*), black gum (*Nyssa*), and persimmon.

As practically all of the plants nearest of kin to those that lived in Jackson time now find a congenial home in tropical or subtropical countries, the conclusion is reached that their climatic requirements were similar, that is, at least subtropical.

At about the same time that the Lower Eocene Wilcox flora just mentioned was flourishing along the Gulf Coast, there was another large flora living in northern New Mexico and southern Colorado, known as the Raton flora. It was quite clearly related to the Wilcox flora, for there were over thirty species common to the two, and many others that were evidently closely related. As great deposits of coal were formed at this time, it is proof of long-continued swamp conditions. There were several small inconspicuous ferns, and a single kind of grass, which was evidently

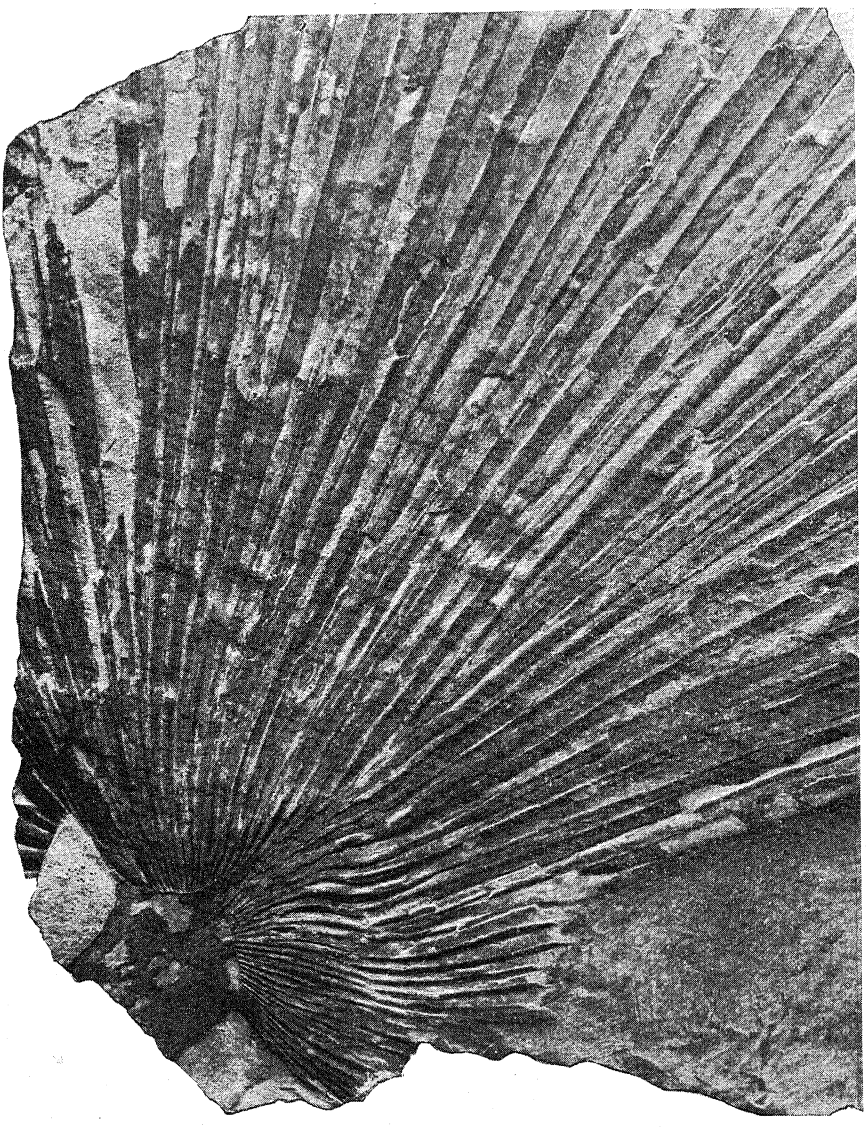


Fig. 80. Leaf of fan-palm (*Sabal inquirenda*) from Raton flora of New Mexico. Much reduced. After Knowlton.

very rare, but no conifers nor cycads of any kind have been found. There were, however, no less than nine different kinds of palms, among them some fan palms with huge leaves four or five feet across. (See *Figure* 80.) These must have been very abundant and striking trees, for their remains are found in dozens of places. There were also nearly twenty kinds of fig trees (*Ficus*), a large-leaved breadfruit tree, several kinds of laurel (*Laurus*) and nearly related trees, as well as three kinds of cinnamon trees. There were also many more familiar trees and shrubs whose descendants live especially in the eastern United States at the present time. Among these was a fine sweet gum (*Liquidambar*), several sycamores (see *Figure* 81), some with very large leaves, a number, probably shrubs or small trees, belonging to the pea family, basswood (*Tilia*), three or four kinds of grapes (*Vitis*) (see *Figure* 82), dogwood, and black gum.

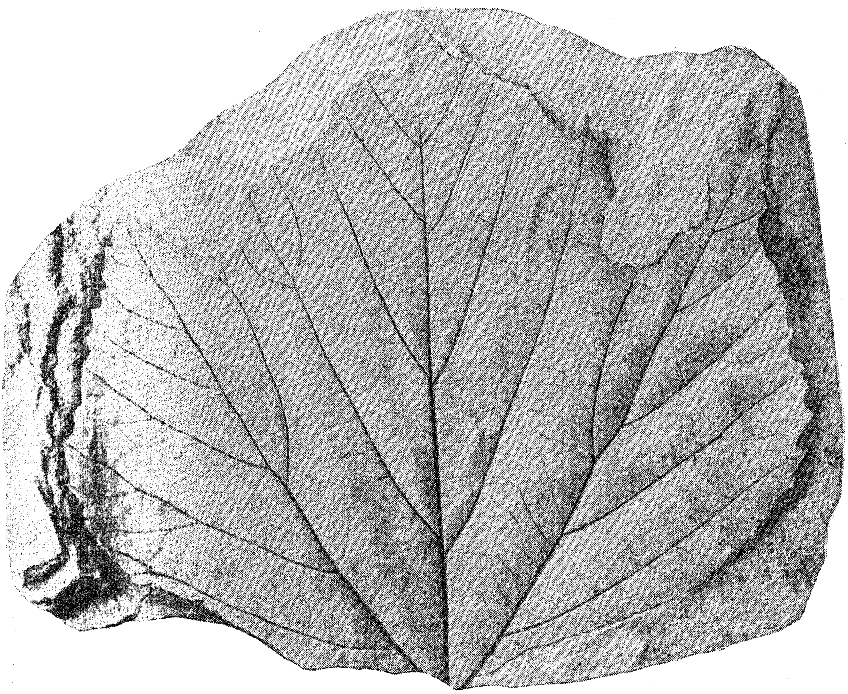


FIG. 81. Sycamore leaf (*Platanus aceroides latifolia*) from the Raton flora of Colorado. After Knowlton.

The Raton flora undoubtedly covered a far larger area in this general region than we now know about. For instance, it is known to have extended northward along both sides of the Rocky Mountains, where, on the eastern side, along the Front Range, it reached the so-called Denver Basin, where the city of

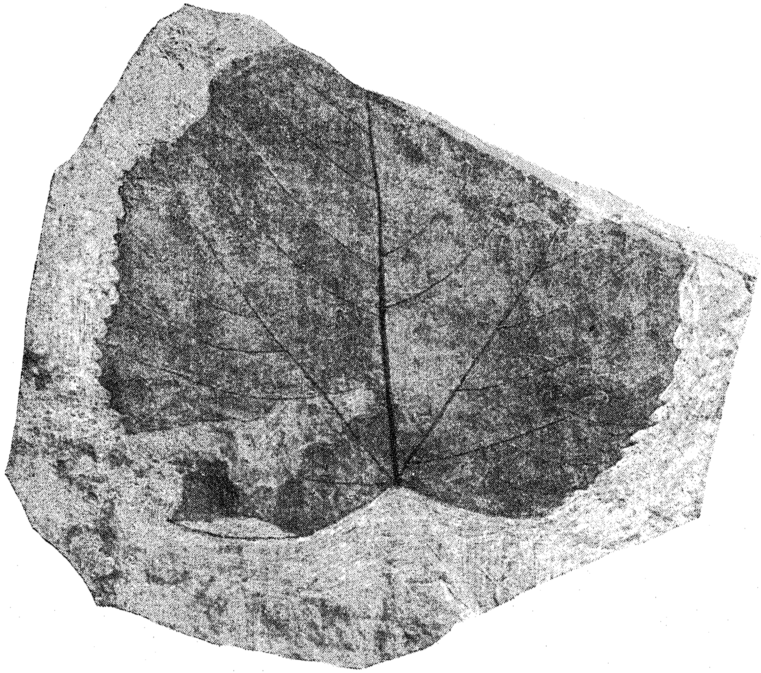


FIG. 82. Leaf of grape vine (*Vitis leei*) from Raton flora of Colorado. After Knowlton.

Denver now stands. It becomes here what is called the Denver flora, of more than two hundred species. Many of these are the same as those found in the Raton flora, but the majority were quite different. It indicates a cooler temperature, though there were still many palms, figs, breadfruit trees (see *Figure* 83), and laurels. The Denver Basin was evidently well watered at this time, and, as a result, the assemblage of plants was very different from the present flora; in fact in many respects it was not greatly unlike the flora of the Eastern Atlantic States at the present day.

Continuing northward, we find that the Denver flora merged

FIG. 83. Leaf of breadfruit tree (*Artocarpus pungens*) from the Denver flora of Colorado. Photograph of specimen in National Museum.

more or less into what is called the Fort Union flora, which covered a vast area in eastern Wyoming, the Dakotas, much of Montana east of the mountains, and thence extending through adjacent parts of Canada, and down the Mackenzie River Valley to the Arctic Coast. At that time this great region was evidently largely a great flat-lying plain, with slow-flowing streams, and

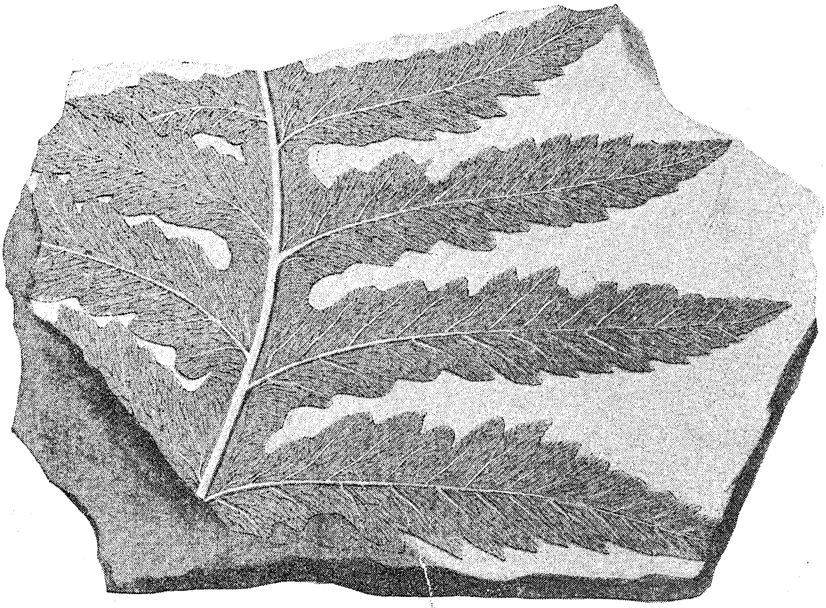


FIG. 84. Frond of sensitive fern (*Onoclea sensibilis fossilis*) from Fort Union flora of Montana. After Newberry.

great marshes and swamps, wherein thick and extensive beds of lignite coal were deposited. Fort Union plants are very abundant and often beautifully preserved, and nearly five hundred species have been collected. It is not possible to give a complete account of this flora at the present time, because it has not yet been fully studied. Enough is known, however, to give a reasonable idea of many of the more important types.

First, it is interesting to note that at least three species that lived in Montana in Fort Union time are believed to be still living. These are the sensitive fern (*Onoclea*) (see *Figure* 84), already mentioned as living in Greenland in upper Eocene time,

and two kinds of hazelnuts (*Corylus*), now widely spread, mainly in the northeastern United States. There were about a dozen species of small ferns, all belonging to modern families, two or three horsetails, and a beautiful little selaginella. Grasses and sedges had become more abundant, but the palms, so conspicuous farther south, had fallen to a single species. It was, however, a very large-leaved fan-palm, showing that conditions were not altogether unfavorable. It is found only near the mouth of the Yellowstone River. Conifers had also become more abundant, due probably, to the cooler climate. There were three kinds of sequoia, one in particular with handsome foliage similar to that of the redwood of California, a yew (*Taxites*), a bald cypress (*Taxodium*) with much larger sprays of foliage than the living species, two or three pines, and a fine little arbor vitae (*Thuya*) that must have been very common, as its remains are found everywhere. There was also an occasional maidenhair tree, or ginkgo, but it was evidently rare.

Undoubtedly the most conspicuous and abundant of the dicotyledonous trees of Fort Union time have been identified as poplars (*Populus*), though they do not agree perfectly with the living poplars. They had small roundish or ovate, coriaceous leaves, usually two or three inches long, on long, often flattened petioles, thus suggesting the leaves of the living quaking aspen, but the nervation was different. More than twenty species have been described, though this is perhaps too many, and thousands of specimens have been collected from hundreds of places throughout the region. The sycamore (*Platanus*) was also conspicuous and abundant, as some half a dozen species have been recognized, some of them with huge leaves twelve or fifteen inches broad, which is as large or larger than those of any living species. Another very abundant and widespread group comprises the viburnums, some twenty supposedly different kinds of which have been recognized. They were presumably small trees or shrubs, known at the present day as arrowwood, blackhaw, tree cranberry, etc. Several supposed oaks have been described, but not all are well authenticated. There were, however, undoubted species of alder, chestnut, hazelnut, maple, elm, magnolia, hickory, walnut, birch, beech, ampelopsis, and bittersweet. The figs and

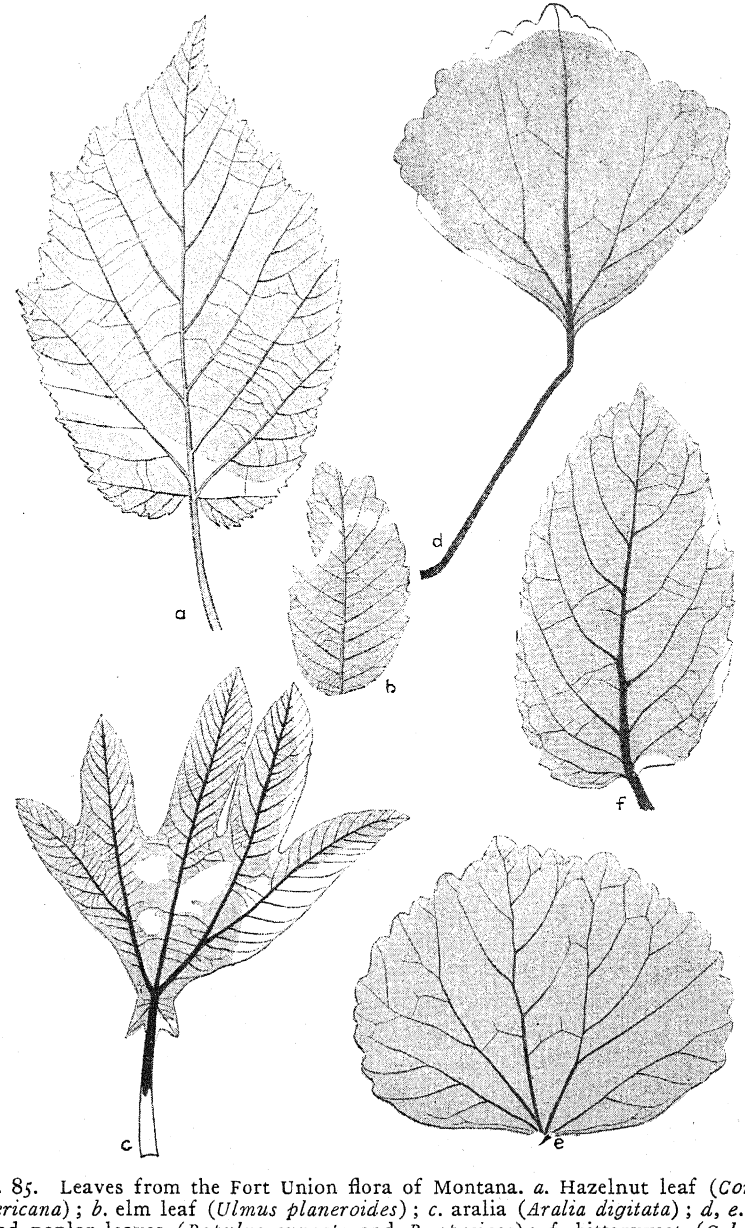


FIG. 85. Leaves from the Fort Union flora of Montana. *a.* Hazelnut leaf (*Corylus americana*); *b.* elm leaf (*Ulmus planeroides*); *c.* aralia (*Aralia digitata*); *d, e.* supposed poplar leaves (*Populus cuneata* and *P. speciosa*); *f.* bittersweet (*Celastrus ferruginea*). After Ward.

laurels were not entirely absent, though they were few in species, and apparently rare as individuals.

But we must leave the region of the Fort Union flora and review briefly the luxuriant vegetation that flourished in late Eocene time in western Washington and nearby areas. This is called the Puget flora. At the time it lived, Puget Sound was greatly enlarged, covering at one time or another a great area from western British Columbia, practically all of western Washington, and reaching far south into Oregon. On the west, bordering the Pacific Ocean, the Olympic Mountains were already in existence, but the Cascade Mountains on the east had not then been built up, at least in the southern part, for beds containing the Puget flora are now found on both sides of the Cascades. This ancient Puget Sound region was alternately above and below sea level, though probably at no time was it much if any over a hundred feet above the sea. As the mountains began to rise in the north, great quantities of sediments were poured into the basin, which slowly sank under the load until a thickness of more than ten thousand feet of beds was built up. During much of the time it was a series of great swamps and marshes, wherein many thick beds of lignite coal were formed. Later, much of this region was covered by a thick mantle of glacial material, on which there now live the most magnifcent coniferous forests that are to be found on the North American continent, but wholly unlike the flora that lived there in Eocene time.

The Puget flora numbers more than three hundred species and, like that of the Fort Union flora, it cannot now be fully described, as it is still incompletely known. The climate was very much warmer than it is now, being very warm temperate, if not indeed bordering on the subtropical. There the setting was similar in many respects to that of the Southern Coastal Plain, already described; in fact, some of the same species occur in both areas. It was probably too warm for most conifers, as very few have been found. Palms were not uncommon, and in some places were evidently abundant, for at one locality east of the Cascades a bed was found nearly a foot in thickness, that was made up almost entirely of fan-palm leaves, some of which were four or five feet in diameter. (See *Figure* 86.) It is interesting to note that several common members of the Puget flora are no longer found on the

Pacific Coast, such as elms, persimmons, and magnolias. What happened to drive them out is not known, though probably it was the result of climatic changes.

From preliminary studies it appears that the near relatives of

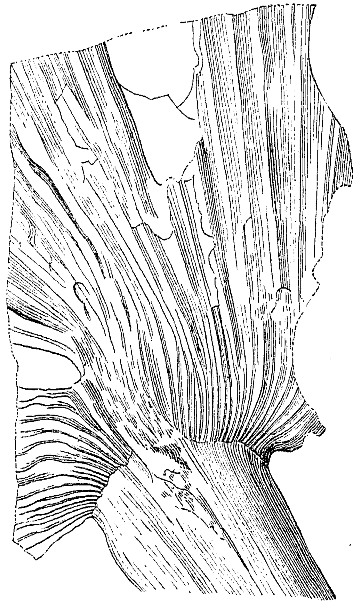


FIG. 86. Fan-palm (*Sabal* sp.) from Puget flora of Washington. Drawing from specimen in National Museum.

many of the Puget plants are now living in southern Mexico, northern South America, and the West Indies. But we must await further studies before this flora can be fully described.

The Puget flora appears to have extended northward into southeastern Alaska, and probably into certain interior portions of Alaska, and from here, there is a more or less evident connection with the flora of Greenland and other Arctic regions, with which this account of the American Eocene floras began.

Chapter XII

THE PLANTS OF MIOCENE TIME

THE Miocene, the middle system of the Tertiary period, was a time during which the continental land masses of the world were largely emergent—that is, there is little evidence of the presence of the extensive inland extensions of the sea, such as had occurred at many previous times. The outline of the North American continent was nearly the same as during the previous Eocene system, but it was much lower. For instance, where the Sierra Nevada and the Coast Ranges of British Columbia now stand, there were flat plains or ranges of low hills, and the Rocky Mountains were much lower than they are now. In the Old World, the Southern Alps and the great Himalayas of India were formed during the Miocene. There was, however, great volcanic activity in the western part of North America. The vast Columbia lava sheet, one of the largest in the world, covered an area of more than 250,000 square miles, mainly in Washington, Oregon, and Idaho. There were also many volcanoes, which sent out great masses of ashes and muds, and this material dammed up streams and produced innumerable ponds and small lakes, especially in the northwest, and it is from the beds deposited in these small bodies of water that most of our knowledge of the plants has come. In the east the deposits were laid down mainly as a narrow fringe along the coasts, and hence are nearly all marine and more or less unfitted for the satisfactory preservation of land plants.

Our knowledge of the flora of North America during Miocene time is comparatively limited since less than seven hundred species have been made known, though presumably there must have been ten thousand or more species then in existence. Undoubtedly a considerable number of these Miocene species are still living, or have come down to the present time with but slight changes, but just what this proportion is cannot be determined at present. It is known, for example, that more than one-fourth of the marine mollusks of Miocene time belong to kinds still living, and possibly the same may hold good for the plants. Our knowledge of the

plants has been supplied from a very few localities, often widely scattered, with only a small number from any one place, in fact, there is only a single deposit, that at Florissant, Colorado, that has thus far yielded more than a hundred species. Another difficulty is presented by the fact that these scattered plant-bearing deposits are often of slightly different ages, and hence there are comparatively few species in common among them.

In all North America east of the Rocky Mountains there is only one deposit, covering a very small area in the District of Columbia and Virginia, that is known to contain plants of the Miocene age, and this, the so-called Calvert flora, has supplied only twenty-six species. Of course this gives a very inadequate and disappointing glimpse of the plants that once clothed half the continent.

The deposit from which this little Calvert flora has come is purely marine, and therefore it is not surprising that the species are few and the individual specimens rare, for salt-water beds are poorly fitted to preserve a land flora. This deposit also contains thick beds of marine diatoms, and several hundred species of mollusks, and from the study of these and other considerations it is concluded that the Calvert sea was shallow, and the climate at least warm temperate.

Probably the most abundant tree in the Calvert flora was the same bald cypress (*Taxodium*) that was shown to have been so common and widespread throughout Eocene time. It is represented by cone-scales, seeds, and branchlets. There were three kinds of small-leaved oaks, one which was closely related to the common white oak of the east, another whose nearest of kin now lives on the arid uplands of the far southwest, and the third very like a species now found along the sandy coast of Georgia and Florida. There was a hornbeam (*Carpinus*) similar to the common hornbeam or water beech now living in bottom lands and swamps from Canada to Florida, a pretty, small-leaved elm, like the winged elm or wahoo, which ranges from Virginia to Texas, a water elm (*Planera*) very close to the tree now living in swamps from North Carolina to Florida and Texas, a sycamore (*Platanus*) like the common sycamore of the eastern states, and several shrubs or small trees of the pea family, some of whose relatives now live in tropical America. There was a sumac (*Rhus*) and a

bittersweet (*Celastrus*) that seem quite distinct from known living species, and a holly (*Ilex*) similar to the so-called yaupon, a shrub or small tree of the south Atlantic and Gulf States. There were also leaves of a *Birchemia*, whose living relative is a high-climbing shrub known as the supple-jack, now found from Virginia to Texas, a black gum (*Nyssa*), a huckleberry (*Vaccinium*) and an ash (*Fraxinus*), all clearly related to living species.

As regards the conditions under which this flora may be presumed to have lived, Professor E. W. Berry, who was the last to study and describe it, says: "The Calvert flora was a coastal flora of strikingly warm-temperate affinities, comparable with the existing coastal floras of South Carolina and Georgia along the south Atlantic coast, or with those along the coast of the Gulf of Mexico from western Florida to eastern Texas."

For our next glimpse of the Miocene flora we must journey westward to the Rocky Mountains, where, at the little town of Florissant, Colorado, we shall find what, in many respects, is one of the most remarkable fossil deposits known anywhere in the world. High up in the mountains, five thousand feet above sea level, there was, in late Miocene time, a little lake—Lake Florissant, it is called—set in the midst of granite hills. It was formed by the damming of a mountain valley, and was only about five miles long and one mile wide. At the bottom of this lake there was formed a deposit, some twenty or thirty feet in thickness, of thin, papery shales, as thin almost as sheets of paper. These deposits were formed largely by volcanic ashes from repeated eruptions falling upon the surface of the water and settling to the bottom, assorted by the sluggish lake currents, and also by mud and ashes falling or flowing into position where they were rapidly washed into the lake by rains, streams, and waves. Most of this deposit was later eroded and washed away, but in the remnants remaining, thousands upon thousands of plant impressions belonging to at least two hundred and fifty species have been collected, as well as over 30,000 insects of more than a thousand species, and remains of fishes, birds, feathers of birds, and shells. From this wealth of material, much of which is exquisitely preserved, we are able to visualize with reasonable certainty what must be a very considerable percentage of the animal and plant forms that lived in and around Lake Florissant.

As might be expected from the elevated position and the distance separating them, the plants at Florissant are totally different from the eastern coastal Calvert flora just considered, and, for that matter, they are very unlike any found elsewhere, except some found in similar little lake beds in south-central Colorado.

Among the plants at Florissant (see *Figure* 87) were several little tufted mosses, some with the delicate fruiting capsules well preserved, about a dozen kinds of small ferns of modern groups, and a single horsetail (*Equisetum*) quite like a living species. Floating on the surface of the water were two kinds of pond weed (*Potamogeton*), and along the shallow margin were quantities of cattails (*Typha*) that are hardly distinguishable from the common living plants. In damp soil there was a quillwort (*Isoetes*), and the tall sword-like leaves and stems of a sweet flag or calamus-root (*Acorus*). This genus has two living species, one a native of Japan, and the other is widely distributed over North America, Europe, and Asia. Two or three grasses have also been found, one (a *Muhlenbergia*) with fruits so like those of a little species known as mesquite grass, now living in Colorado and Texas, that they can hardly be separated.

Cone-bearing trees must have been conspicuous and abundant in the swamps and on the hills about the lake. In one place there is a veritable, though small, fossil forest of sequoias, some with trunks six or eight feet in diameter; it is apparently related to the living redwood. Another exceedingly abundant tree, also a sequoia, is represented by pieces of all sizes, from single slender twigs up to forking branches and branchlets covering a square foot or more in area. These often show the male aments and mature cones, all in completeness of detail but little inferior to living material. This is almost identical with the living redwood, and probably represents the foliage and cones of the trunks just mentioned. There were four pines (*Pinus*), one with cones three or four inches long, suggesting the yellow or bull pine, which now ranges from British Columbia to Mexico, and three known only from the leaves. Doubtless the cones belong to one known from the leaves, but as they have not been found attached it is impossible to tell which one. Another had leaves four or five inches long in clusters of five, showing that it belonged to the white pine group. Another conifer that was evidently very abundant

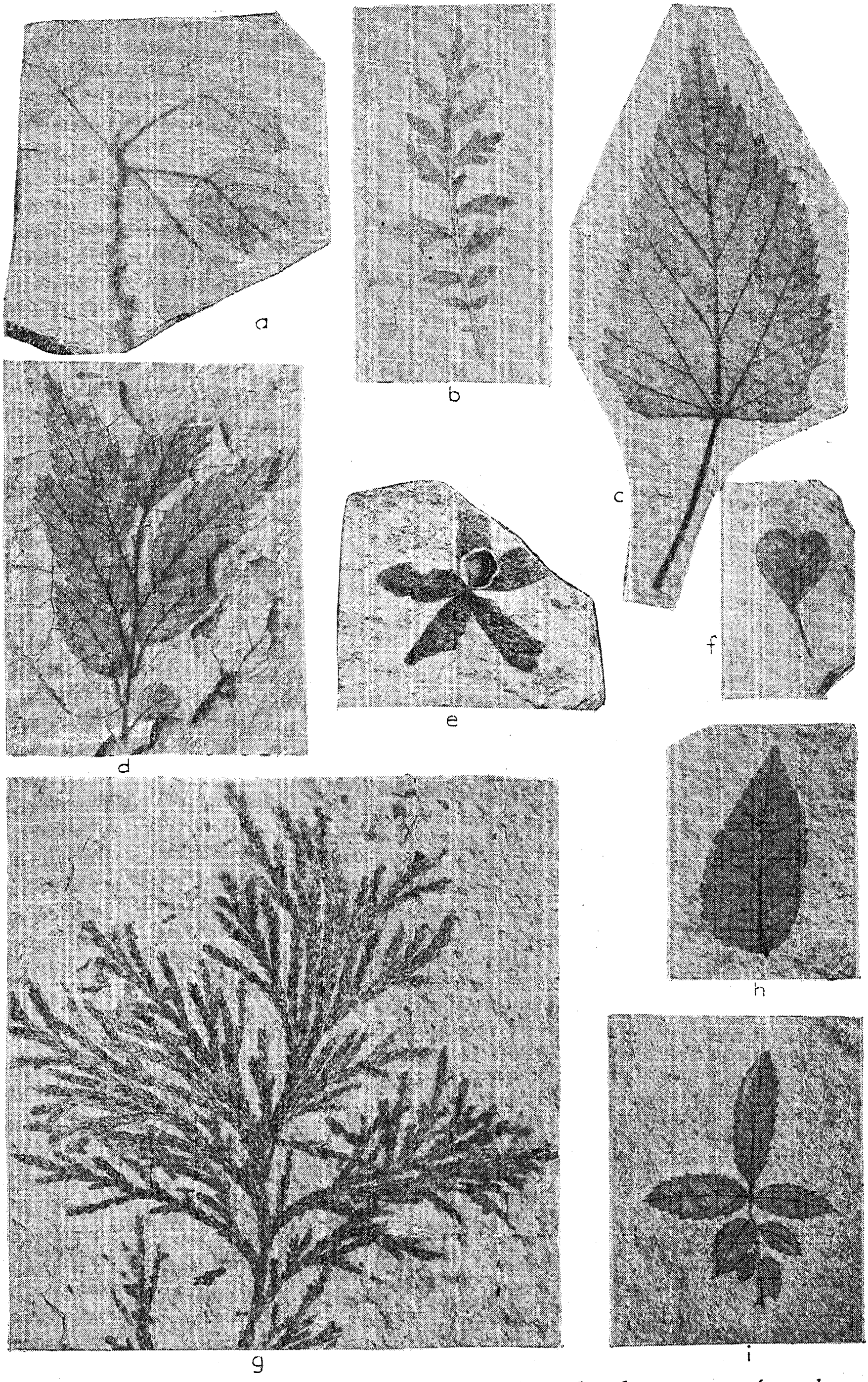


FIG. 87. Plants from Miocene lake beds, Florissant, Colorado. *a.* Aspen (*Populus microtremuloides*); *b.* lomatia (*Lomatia interrupta*); *c.* white birch (*Betula deltoides*); *d.* beechnut (*Fagopsis*); *e.* flower (*Porana tenuis*); *f.* rosewood (*Dalbergia minuta*); *g.* creeping juniper (*Sabina linguaefolia*); *h.* ash (***Fraxinus***); ***i.*** rose leaf (***Rosa*** *scudderi*). Photographs from specimens in National Museum.

was a little juniper (*Juniperus* or *Sabina*) with slender, graceful branchlets. Its nearest of kin is a prostrate shrub forming dense mats on dry ridges in the high mountains.

Probably living on the shores of the lake, or along the banks of streams flowing into it, were four or five very modern looking willows, and no less than seven supposedly distinct species of poplar (*Populus*). One of the latter shows clusters of small, round, long-petioled leaves very similar to those of a stunted branch of the common quaking aspen now living in the region. There are also long drooping clusters of fruiting capsules like those of the cottonwood. A few leaves apparently belonging to a sweet-fern (*Comptonia*) have been found, and six species of wax-berry (*Myrica*), one of which is by all odds the most abundant plant found in these shales. It must have grown in great profusion. There were eight species of ash (*Fraxinus*), seven supposed different kinds of holly (*Ilex*), three or four each of hickories (*Hicoria*) and walnuts (*Juglans*), but curiously enough no sycamores have been found. The oaks (*Quercus*) were especially numerous, there being nearly a dozen species recognized, among them some that are hardly distinguishable from living forms. One, for instance, with deeply lobed leaves, is very close to the overcup or post oak (*Quercus lyrata*), now ranging from New Jersey to Florida and Texas, while others are similar to certain scrubby species now living in the southwest. Mention should also be made of a tree called *Fagopsis*, known from both leaves and fruits, that is hardly to be distinguished from the living beech (*Fagus*); it was evidently very abundant. There were two or three elms (*Ulmus*), no less than five kinds of maple (*Acer*), several buckthorns (*Rhamnus*), sumacs (*Rhus*), soapberries (*Sapindus*), a supposed persimmon (*Diospyros*), bittersweet (*Celastrus*), hackberry (*Celtis*), a small linden (*Tilia*), two wild grapes (*Vitis*), a wild currant (*Ribes*), and not less than five wild roses (*Rosa*). The pea family, taken in its original and widest sense, has several representatives, such as acacia and a locust (*Robinia*). Herbaceous plants are always rare as fossils, and the Florissant beds are no exception, though there are a few, such as a frog's bit (*Limnobium*) and a buck bean (*Menyanthes*), both marsh plants, and a supposed saxifrage (*Saxifraga*), a smartweed (*Persicaria*), a monkey flower (*Mimulus*), milkvetch (*Phaca*),

and a supposed mallow (*Malvastrum*). As some of these rest on a single specimen their identification is often open to more or less question.

The Florissant plants thus far mentioned all belong to the familiar and well known genera, with living representatives in various portions of North America, many indeed in the Rocky Mountain region. There are, however, a number no longer native in this country, but are found scattered, many of them in far distant parts of the world. Thus, ailanthus, or the so-called tree-of-heaven, has three living species found in China and the East Indies. The Florissant species is closely related to the Chinese tree (*Ailanthus glandulosa*), which is now naturalized in many parts of the eastern United States. *Engelhardtia*, a tree belonging to the walnut family, is known at once by its large three-winged involucre, which resembles, and has often been confused with, the same organ in the hornbean (*Carpinus*). This genus, with about ten living species in the southeastern Asiatic region, has one closely related or perhaps identical species in Central America. *Amygdalus*, the genus to which the peach belongs, embraces five species, all natives at the present time of eastern Asia. *Sterculia* is a large group of about one hundred species of handsome trees mainly with large-lobed leaves and a large capsular fruit. It is found now in the tropics of both hemispheres, yet two well-marked species still lingered in North America in Florissant time. Five or six species are referred to *Lomatia*, a genus of about ten species of trees now living in Australia, Tasmania, and Chile. *Porana* (see *Figure* 87 *e*), a group of climbing plants of the morning glory family, now confined to the East Indies, was represented by four characteristic species in the Florissant flora. These are based on the capsules and their surrounding calyx segments. *Porana* occurs in the Miocene in Europe, but only at Florissant in North America. Several other trees no longer native in North America have been reported from Florissant, but as their identification is somewhat uncertain, they may be passed over.

Although there has not been space to mention all of the plants found in the Florissant shales, enough have been enumerated to show that the flora was overwhelmingly North American, as might be expected, yet there are a considerable number that have disappeared as natives, and now appear in widely separated parts

of the world. This illustrates clearly some of the striking changes that have come about in plant distribution since Miocene time, due probably in large measure to the Pleistocene Ice Age. The plants that lived in Florissant time indicate that there was more moisture in that region than at present, though it was not excessive. The temperature, too, was higher than now, though by no means tropical or even sub-tropical. It was perhaps not unlike the climate of North Carolina at the present day.

The next largest Miocene flora known in North America, and numbering about a hundred species, is that found in the vicinity of Spokane, Washington (see *Figure* 88). This is at the extreme edge of the great Columbia lava sheet, and as the lava poured out, it advanced over a rugged mountain country, filling the valleys and flowing around the hills and headlands, much like the coast line of the sea. It dammed up a stream coming down from the mountains to the northeast, now largely the bed of the Spokane River, making a shallow lake several miles in length, and before the lake was finally drained there had been accumulated a thickness of several hundred feet of clays and shales, wherein the plants are preserved. Much of this old lake bed was later eroded and washed away, but enough remains to afford a fair idea of the plants that once lived in and around the lake. Most of the plants are found in soft, fine-grained clay, and are often beautifully preserved.

There are several little tufted mosses, all belonging to extinct genera, but strangely enough only a single minute fragment of a fern has been found. There was, however, a fine little ground pine (*Lycopodium*), whose nearest of kin now lives in the pine barrens of New Jersey and southward. Grasses were present but they are too fragmentary to be recognized. Pond weeds (*Potamogeton*) and cattails (*Typha*) were also present, but they appear to have been very rare.

Coniferous trees must have been a very conspicuous feature in this flora, the one most abundantly represented being the bald cypress (*Taxodium*) so often mentioned (*Figure* 88 *e*). This is the commonest plant found in these beds, and literally hundreds of more or less perfect branchlets have been found. It doubtless grew in the swamps bordering the lake. Almost equally abundant is a sequoia (*Sequoia langsdorfii*), a tree that is widely distributed

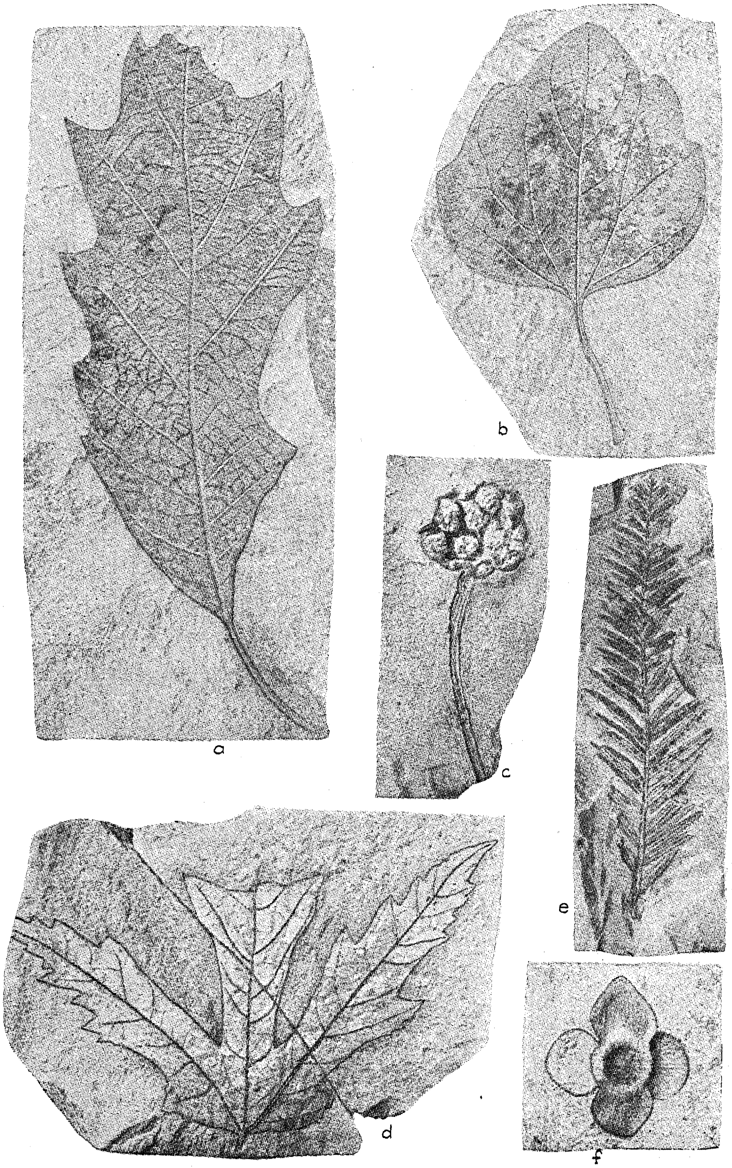


FIG. 88. Leaves and fruits from Miocene beds, Spokane, Washington. *a.* Oak (*Quercus cognatus*); *b.* poplar (*Populus heteromorpha*); *c.* Indian turnip (*Arisaema*); *d.* maple (*Acer chaneyi*); *e.* cypress (*Taxodium dubium*); *f.* calyx of persimmon (*Diospyros andersonae*). Photographs from specimens in National Museum.

in the Tertiary of Europe, Greenland, and North America. It is clearly related to the California redwood, and indeed appears to have been its direct ancestor, probably crowded southward to its present home by the cold of the Pleistocene Ice Age. There were two trees that must have been rare, at least if we are to judge from the fact that only very small fragments have thus far been observed, though they may have lived on the high mountains back from the lake, and not in position to be carried into it. There are an incense cedar (*Libocedrus*), that can hardly be distinguished from the species now living in the mountains of Oregon and California, and a tree called the stinking cedar or California nutmeg (*Tumion*). There are four living species of *Tumion*, one found along the Appalachicola River in Florida, another in California, and the remaining two in Japan and China. The Spokane tree is very similar to the California species, and may well have been its immediate ancestor. There were also two pines, one with the leaves in clusters of three, showing it to be a hard pine, but both are imperfectly represented. Undoubtedly the most interesting tree of this group is the ginkgo or maidenhair tree (*Ginkgo*), which, so far as we now know, made its last stand in North America in the Spokane region. Only three of the leaves have been found, but they are so perfectly preserved that they could be taken almost unbroken from their clay tomb, and mounted between pieces of glass, and except for the fact that they are now perfectly black, they can hardly be distinguished from a fresh leaf. (See *Figure* 3.) At the present time the ginkgo is found native only in China and Japan.

The willow family (*Salicaceae*), which comprises over two hundred living species of north temperate and Arctic regions, was represented by six kinds of willow (*Salix*), all with very modern looking leaves, and four kinds of poplars (*Populus*). One of the latter, called *Populus heteromorpha* (*Figure* 88 *a*), was, next to the bald cypress mentioned above, the most abundantly represented tree in the Spokane deposits. It seems to be more closely related to the white or silver-leaf poplar, a native of Europe and Asia, than to any North American species.

The birch family (*Betulaceae*) includes the so-called cones of an alder (*Alnus*), and five or six species of birch (*Betula*), several of which are evidently rather closely related to a number

of living birches. The oak family (*Fagaceae*) was abundantly represented by a handsome chestnut (*Castanea*), and a full dozen oaks, some based on the acorns and acorn-cups, but mostly on the leaves. The majority of these belong to the red oak group (see *Figure* 88 *a*), with deeply cut, spine-tipped lobes, though there are several that were evidently thick-leaved evergreens, suggesting the live oaks of the Southern States. There were two kinds of elm (*Ulmus*), a magnolia, a sweet gum (*Liquidambar*) with smaller, thicker leaves than the familiar sweet gum of the eastern United States, a sumac (*Rhus*) with long, narrow leaflets, and three or four maples (*Acer*), all looking so much like certain species living in California and elsewhere that they can hardly be separated. Another very interesting tree was a persimmon (*Diospyros*) that is so similar to the common Virginia persimmon of the East that it is hardly possible to see any difference (*Figure* 88 *f*). There are about one hundred and fifty living species of persimmon, nearly all natives of tropical countries, with a very few extending into temperate regions. The United States has only two species, the one just mentioned, and a smaller fruited one living in Texas. The common Virginia persimmon does not now live within a thousand miles of the Spokane region, yet what must have been its immediate ancestor lived there in Miocene time. It was probably exterminated in that region by the great Ice Age, and has never been able to regain the lost ground.

There are quite a number of the species of trees and shrubs of the Spokane region that have been found in Oregon, Nevada, and California, showing that this Miocene flora was once spread over a large area in the western states. There are a dozen or more places at which they have been found, though usually only comparatively few kinds are thus far known from any one locality, and yet each generally adds something not found elsewhere. Probably the richest of these scattered deposits is that known as the Mascall flora, found in the John Day Basin in western Oregon. (*Figure* 89.) The beds at this locality are made up largely of a fine-grained volcanic ash or glass, showing that there was an active volcano not far away. This rock is so light and porous that when a piece of it is thrown out in a stream it actually floats away like a piece of wood.

About eighty different kinds of plants have been found in the

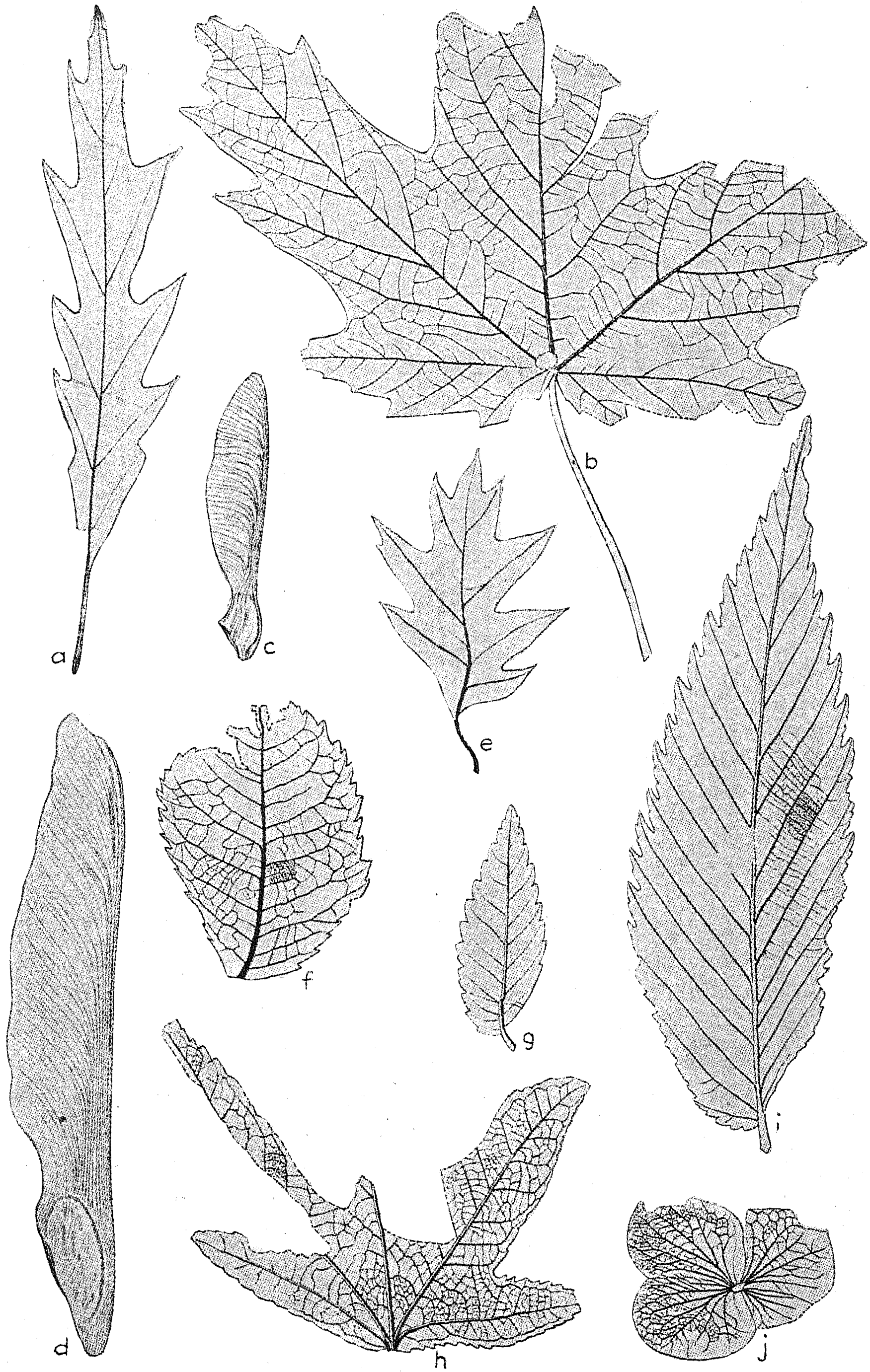


FIG. 89. Leaves and fruits from the John Day Basin, Oregon. *a.* Oak (*Quercus merriami*); *b.* maple (*Acer osmonti*); *c.* maple fruit (*Acer medium*); *d.* maple fruit (*Acer gigas*); *e.* oak leaf (*Quercus*); *f.* plum (*Prunus*); *g.* bayberry (*Myrica*); *h.* sweetgum (*Liquidambar*); *i.* elm leaf (*Alnus*); *j.* sterile flower of snowball (*Hydrangea*). Photographs from specimens in National Museum.

Mascall flora, and among those found also in the Spokane region, mention may be made of *Sequoia langsdorfii* which is so abundant in the former area; also the same bald cypress (*Taxodium*), a poplar, the only one found in the Mascall beds, and two or three willows (*Salix*). There is also a hornbeam (*Carpinus*), at least three species of oak, a magnolia, the same thick-leaved sweet gum, flowers of the snowball (*Hydrangea*), as well as three maples. There was also a persimmon, but as it is known only from the leaves, and the Spokane species only from the thick leathery calyx, it is not possible to tell whether or not they are the same.

Among the more conspicuous of the species in the Mascall flora that have not been discovered elsewhere, is a handsome smilax, a walnut, a hickory, two elms, a sycamore (*Platanus*), two supposed plums (*Prunus*), a horse-chestnut, and two or three kinds of soapberry (*Sapindus*).

At about the same time that the Miocene floras just described were living in North America, there was a very large Miocene flora living in central Europe, especially around the present Lake Constance in Switzerland and in nearby parts of the province of Baden, Germany. (See *Figure* 90.) The beds containing this rich flora were deposited in fresh-water lakes, and are made up largely of white, fine-grained material that is admirably adapted for preserving the delicate parts of the plants in a high degree of perfection. This flora was studied and described many years ago by Professor Oswald Heer, one of the most distinguished students of fossil plants who ever lived, and his results are set forth in three large quarto volumes, with over one hundred and fifty plates and many hundreds of beautifully drawn figures. Heer named and described nearly a thousand different kinds of plants, and it is estimated that the whole flora when living must have numbered some two or three thousand; in any event a number far greater in many groups than are growing in the region at the present day. These plants have been found at more than eighty localities, one of the richest being at Oeningen, in Baden, which has supplied nearly five hundred species. Altogether these localities are probably the richest plant deposits known anywhere in the world.

Dense forests covered Switzerland and adjacent areas in Miocene time. Heer has recognized 533 species of woody plants, of

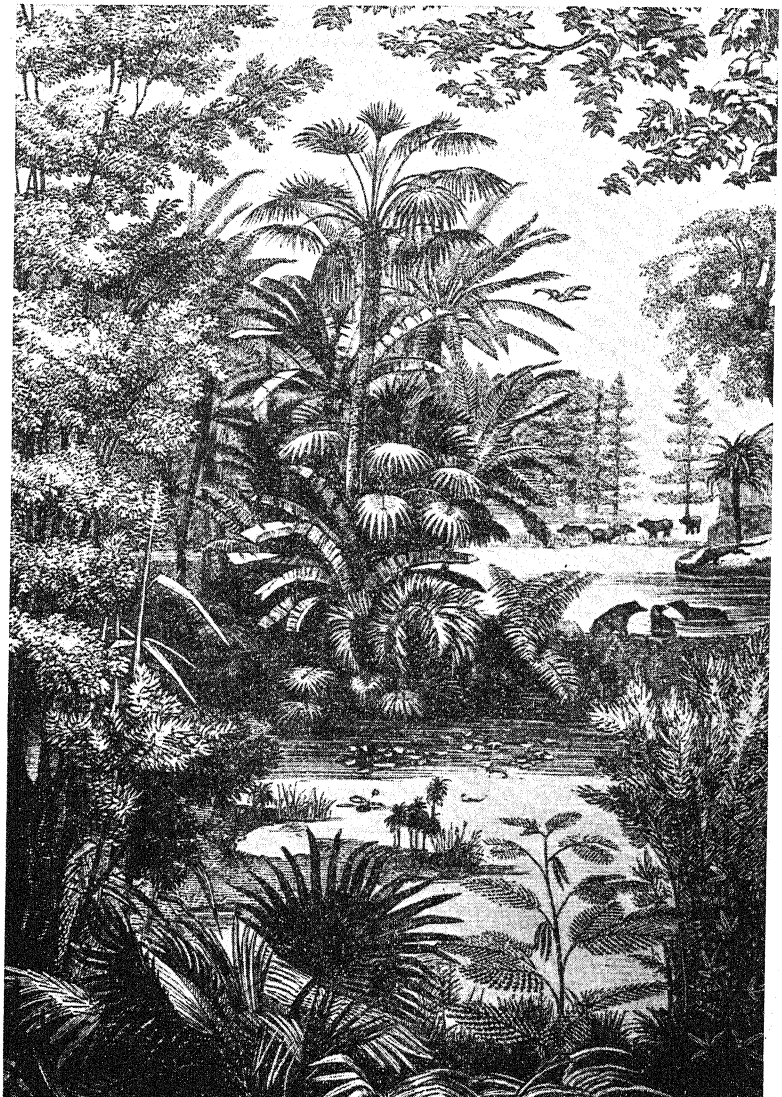


FIG. 90. Switzerland during the Miocene period. In the foreground are splendid fan-leaved and feather-leaved palms; at left is a tall camphor-tree (*Cinnamomum*), with laurel bushes at its base; on right an *Acacia* tree with large pods, clumps of willows with climbing ferns clambering over them, and above a branch of a cut-leaved maple; on the lake are water-lilies and lotus, with sedges and reeds in the shallower water; in middle distance a group of palms, both fan- and feather-leaved; in the background is a group of white pines, a walnut tree, and a spiny-leaved pineapple-like plant; in the distance may be seen rhinoceroses, and the nearer ones are tapirs, while on the right a crocodile is basking in the sun. After Heer.

which 291 were trees, and 242 were classed as shrubs, and there were also 164 kinds of herbaceous flowering plants, and a large number belonging to the lower groups, such as fungi, mosses and ferns. The example of a similarly rich woody vegetation is found in the valleys of the Orinoco and the Amazon, and many other tropical parts of the world.

Since these wonderful forests were living in central Europe, many strange changes in plant distribution have come about, induced largely by the lowered temperature of the Pleistocene ice invasion. Very few were able to pass over the great mountain masses to the south, though some were able to escape to the eastward, and their descendants now live in eastern Asia, and not a few were banished forever from Europe, and indeed from the Old World. Take for instance the palms. At the present time there is only a single kind, a dwarf fan-palm (*Chamacrops*), now living in Europe, yet in middle Miocene time there were a full dozen species living in Switzerland, proving conclusively that the climate must have been much warmer then than now. Among them were both fan-palms and feather-leaved forms, some with leaves two feet long, and probably with lofty trunks. Their nearest of kin are now widely scattered—in the West Indies, Brazil, Florida, and far to the east, in tropical India.

Some of the coniferous trees will illustrate this distributional change. Thus the bald cypress (*Taxodium*), so often mentioned before in describing the North American fossil forests, once lived in Switzerland as well as in Italy, Germany, Spitzbergen, and Greenland. Its present home is in the eastern United States and Mexico. The sequoias, now living only in California, were represented by several species in the Swiss Miocene, among them being *Sequoia langsdorfii*, the near relative of the redwood, and which also spread from central Italy and Greece up to the Arctic zone. Another, called *Sequoia sternbergii*, is closely related to the big trees of California. Though rare in Switzerland, it has been found at many places in Italy and Germany. Probably the most abundant tree, not only in Switzerland, but throughout Europe, was the *Glyptostrobus europaeus*, a kind of cypress, whose near relative is now found in China and Japan. There was also an incense cedar (*Libocedrus*), related to the species living in California

and Chile, and a *Widdringtonia*, whose nearest of kin is now found only at the Cape of Good Hope and in Madagascar.

Willows and poplars were abundant. At the present day there are only four kinds of poplar living in Switzerland, but in Miocene time there were twice that number, among them being representatives of four groups, namely the aspens and black poplars, now found in Europe, Asia, and America, the balsam poplars of America and Asia, and the leather poplars now known only in Asia. Of many of these the branches, leaves, flowers and fruits are known. There was also a sycamore and a sweet gum (*Liquidambar*), both abundantly represented by leaves and fruits, and both closely related to trees now living in the eastern United States. The oaks were particularly numerous, and Professor Heer has recognized no less than thirty-five supposedly different kinds, and these almost without exception are species with leathery, apparently evergreen leaves, sometimes entire, sometimes toothed or even spiny on the edges, much like many now living in North America and in the Mediterranean regions. There were also alders, birches, elms, a plane-tree or water elm (*Planera*) allied to one now inhabitating the Caucasias, several waxberries (*Myrica*), and a large number of fig trees.

There are, of course, a great many other trees, shrubs, and herbs that it would be interesting to mention, but we have space for only a few that are of particular interest. The tulip tree or yellow poplar (*Liriodendron*), now represented by two species, one living in the eastern United States, and the other in central China, has had a long and remarkable geologic history. So far as now known, it began in the lower part of the Upper Cretaceous along the Atlantic border in New Jersey, and soon spread in a dozen or more species in the Upper Cretaceous of many parts of the world. In the succeeding Eocene time, tulip trees were found in British Columbia, Greenland, Iceland and England, and in Miocene time they were present in Switzerland, Italy and Bohemia, in forms hardly to be distinguished from the living tree. They were still present in Europe in Pliocene time, but the great ice invasion of the Pleistocene drove them permanently out of Europe, and, a vanishing race, they are making a last stand on opposite sides of the Northern Hemisphere, in North America and China.

The maples (*Acer*) were a very important group in the Miocene flora of Switzerland, and their species, Heer says, "were more numerous than they are at present in any country of the world." At the present time there are only five or six kinds living in Switzerland and Germany, yet in Miocene time there were twenty species, of which number sixteen lived in the forests of Oeningen. Although several of these are not very well authenticated, there were ten or more of which leaves, flowers, and fruits are fairly well known. On the whole these maples seem to be most like North American forms.

In addition to the plants, over eight hundred different species of insects have been found in the Miocene rocks of Switzerland, and from the careful study of these insects, and a knowledge of the food habits of their living relatives, it is possible to infer the presence of certain kinds of plants although their remains have not been found.

There were undoubtedly many Eocene floras living in the Old World that were contemporaneous with certain of the floras living in North America and Greenland, but unfortunately our knowledge concerning them is still very incomplete. The known Eocene floras of the vast continent of Asia, for example, are so small as to be practically negligible, and until this need can be supplied—as it may be with more extensive exploration in central and northern Asia—the picture must be painted with light strokes.

The most complete of the Old World floras are found in western and southern Europe—in England, Belgium, France, and Italy, which together have yielded perhaps a thousand species, but as we shall see, fully half of this number are still unavailable for study and comparison although they have been known for nearly half a century. The most extensive of these floras are found near the mouth of the Thames, at Alune Bay and the Isle of Sheppey, which have supplied nearly two hundred genera and about five hundred species. Most of these, however, are known only from a list of generic and specific names, unaccompanied by either descriptions or figures. On comparison it is seen that a large proportion of the genera in these English beds are the same as those that lived in North America during some stages of the Eocene, and it is more than probable that many of the

species will be found to be identical or closely related. Climatic conditions are indicated in various ways but especially by the presence of five or six genera of palms, among them being the large and very characteristic woody fruits of the stemless or nipa palm (*Nipadites*). The only existing species (*Nipa fruticans*) is a low-growing palm of the Old World tropics, which lives in brackish water just back of the mangrove fringe, where it covers large areas of tropical coasts. No less than five nominal species of *Nipadites* are listed from these English beds, one of which has been found in the Wilcox flora of Mississippi, thus proving that this palm was once native in the New World. It is inferred from the presence of these palms, as well as of other warmth-loving plants, that England at this stage of the Eocene was much warmer than now, that is, sub-tropical or possibly tropical.

On the Island of Mull, off the west coast of Scotland, there is a small Lower Eocene flora that contains a number of species closely related to, or possibly identical with, forms found in the Fort Union flora of Montana, such as the sensitive fern (*Onoclea*), the hazelnut (*Corylus*), and sycamore (*Platanus*). There were also several conifers, among them a *Sequoia* similar to our redwood, and a supposed *Podocarpus*, a genus of broad-leaved conifers not now native in the Northern Hemisphere.

Chapter XIII

PLANTS OF PLIOCENE TIME

DURING the Pliocene, which was the closing epoch of the Tertiary period, the oceans were more completely excluded from the great continental land masses than during the preceding Miocene and Eocene epochs, and consequently rocks deposited in marine waters were greatly reduced. There were of course deposits of this age laid down on the land, that is, in fresh waters, but they are widely scattered, very incompletely studied, and rarely plant-bearing, with the result that our knowledge of the plants that must have been living in North America during Pliocene time is almost negligible. For instance, less than fifty species of Pliocene plants are at present known from the whole of North America, and hardly more than five hundred species for the entire world. From this small number it is quite impossible to reconstruct much of a picture of the Pliocene flora, though if the proportion between the living and extinct species holds for the plants, as it is known to do for certain groups of animals, then eighty or ninety per cent of the Pliocene plants belonged to forms now living, and of these there must have been many thousands. The lowering of temperatures over the northern hemisphere, especially during late Pliocene time, foreshadowing the coming of the Great Ice Age, undoubtedly had a profound effect on the distribution of plants, forcing some to the wall, and others to migrate, often to distant lands.

The best known of the scant North American Pliocene floras is found in southern Alabama, and is called the Citronelle flora. It includes only eighteen species, three of which, the bald cypress, the water oak (*Quercus nigra*), and the water elm (*Planera aquatica*), are still living in the region at the present day. The others, although regarded as extinct, are closely related to living forms, mostly living nearby. These include a birch tree, a beech, several evergreen oaks, a small fruited hickory (*Hicoria*), a black gum (*Nyssa*), and, more or less doubtfully, are ash, plum, grape, and a supposed yucca. Perhaps the most interesting plant is

known as the water chestnut (*Trapa*), which is represented by its large horned fruits. This plant, living especially in shallow ponds and slow-moving streams, is no longer a native of the New World. Several well-marked species of *Trapa*, based also on the fruits, are known from beds of Eocene and Miocene age in western North America, but it appears to have made its last stand in this country in the Pliocene of Alabama. It is impossible to explain why it failed here, especially as one of the Old World species has been introduced at several points in the eastern United States and appears to thrive well.

Another small flora of some twenty species is found in the Santa Cruz Mountains of California. They are all supposed to be plants living in the vicinity at the present time, but they are doubtfully identified, and hence of little importance.

Knowledge of the Pliocene flora of Europe is far more complete than is that of North America, and yet even this is evidently but a mere fragment of the once existing flora. The most completely studied deposits are found along the Dutch-Prussian border, mainly in adjacent Holland. In the area between the Maas and the Rhine, where these rivers leave the highlands and enter the plains of the Netherlands, they have cut through a series of terraces some three hundred feet in thickness composed mainly of sands and clays that were deposited in what was once evidently a great estuary. Two principal localities for plants are known, and for the study of these we are mainly indebted to Mr. and Mrs. Clement Reid, who are well known for their extensive studies of the Pleistocene floras of England.

The lowest and oldest of these floras, believed to be of Middle Pliocene age, is called the Reuverian flora, so named from a small town in the vicinity. The plants recovered are almost entirely seeds and fruits, many of them of minute size and extremely difficult to identify. About three hundred species of plants have been found, but of these there were about seventy species that could not be placed, even within a family. Of the two hundred and thirty remaining species recognized with a measure of certainty, some one hundred and seventy-five species were identified with what is considered to be absolute certainty. At first it was thought that the affinity of the Reuverian flora would be with the flora now living in western Europe, but it was found to be almost

entirely different, and, as the Reids were led further and further afield in their comparisons, it was ultimately discovered that the closest agreement was with plants now living on the mountains of western China and its allied geographical provinces, Japan, the Himalayas, Tibet, and the Malay Peninsula. This amounts not only to many absolutely identical species (in the genera *Gnetum*, *Stewartia*, *Magnolia*, *Zelcowa*, *Pyrularia*, *Prunus*, etc.), but to many very closely related species. Curiously enough, when a genus still lives in Europe and the Orient, it is often the Chinese or Japanese species that most resembles the Reuverian plant. There are of course a few species found in the Reuverian flora that are still living in Europe, or are more closely related to those of Europe than to those of China, such as the Norway spruce (*Picea excelsa*), European oak (*Quercus robur*), filbert (*Corylus avellana*), ironwood (*Carpinus betulus*), and European grape (*Vitis vinifera*), but the kinship with the Chinese province holds good.

Nearly thirty of the Reuverian plants are found, either in identical or closely related forms, in North America, the most notable being the eel grass (*Naias marina*), arrowhead (*Alisima plantago*), hickory nut (*Hicoria alba*), water-shield (*Brasenia purpurea*), and tulip tree (*Liriodendron tulipifera*). Several of these North American species are no longer living in Europe.

The uppermost of the two Dutch Pliocene floras is known as the Teglian flora, and is placed in the Upper Pliocene. It comprises about one hundred and thirty species, which tell a story very different from that of the Reuverian flora just considered. There are a few species that are found also in the Reuverian flora, as well as a number common to the Oriental region, but on the whole it is quite distinct, and undoubtedly finds its closest relationship with the flora now living in central Europe. It indicates distinctly a cooler temperature than that indicated by the Reuverian flora, and hence many of the plants were able to survive in the region to the present day.

We may now consider the significance of these Pliocene floras, that is, whence they came, how they reached their present location if still living, or how they came to be exterminated. At the beginning of Pliocene time, and of course still earlier, these floras were practically circumpolar in distribution, and an indication

of at least a warm-temperate climate. The oncoming of the cold that foreshadowed the Ice Age was undoubtedly very gradual, and as the plants were slowly pressed southward, they had open before them three principal avenues of escape. One, perhaps the broader pathway, was down through the lowlands of eastern Asia by way of the coastal plains of China, and the great valley systems of that country, finally reaching the warm temperate and subtropical regions. This great continuous stream of migrants pressed southward, some in the valleys, others along the ridges, to mingle with the original floras, but, when the Glacial period developed, some of the warmer elements probably perished, while others survived by seeking the lower valleys where they became inured to slightly cooler temperatures. Then, when warmer, more favorable conditions returned, during the interglacial periods, the valleys proved too warm, and again the plants escaped by ascending the mountain slopes. As there were several glacial and interglacial intervals, this climbing and descending the mountain slopes probably was several times reversed, but the final result has left them in congenial homes where we find them today. This mingling of the northern floras with those already existing explains the great richness of the present Chinese flora, which is one of the richest temperate floras in the world.

In North America the north-south trend of the mountain ranges left another avenue of escape open to the tropics, and many species of plants came by this route to enrich the American flora. This of course explains the marked similarity between the floras of eastern North America and eastern Asia, a condition noted many years ago by Asa Gray, one of America's most distinguished botanists, and since commented on and augmented by many others. This resemblance extends not only to many genera with closely related species, but to many identical species, in the two now widely separated areas, such as the tulip tree, sassafras, and bald cypress. A recent study of the flora of the Island of Yezo, which lies north of the main island of Japan, discloses that more than twenty-six per cent of its plants are found also in North America. This present distribution on opposite sides of the globe is unexplainable on any other basis.

The third migration route for the warm floras of the north, as they were forced southward by the increasing cold, was down

the Scandinavian Peninsula and adjacent areas into central and western Europe, but here the conditions are very different from those just considered in North America and eastern Asia. The great mountain ranges (Alps, Pyrenees, Carpathians, Balkans, Caucasias), instead of trending north and south, all trend east and west, thus effectively closing easy access to the tropics. That many of the northern plants actually reached western Europe is abundantly shown by the presence of their remains in the Reuverian flora, but, as the cold increased, they were forced against the huge mountain barriers and so perished. Doubtless some of these plants, especially those with very small seeds, succeeded in passing over the mountains, for as shown by Hooker and others, a mountain mass is not an absolute barrier, but even then they were not out of danger, for although the temperature may have been sufficiently high, there was a deficiency of moisture, and so with very few exceptions they were permanently exterminated in central and western Europe.

The Teglian flora of the late Pliocene is very different from the Reuverian flora, and apparently had two centers of distribution or origin, one by the way of Scandinavia, and the other by the mountains of central Asia, whence it radiated in several directions. It was a cool-temperate assemblage, and hence when it was pushed southward by the advancing cold, much of it was able to survive. Some of the members of the Reuverian flora continued to Teglian time, and there is also a noticeable oriental element, but taken altogether its affinity is clearly with the present flora of central Europe.

This brief review will serve to show the profound effect on the present distribution of plants as a result of forces inaugurated during Pliocene time.

Chapter XIV

THE PLEISTOCENE OR GREAT ICE AGE AND ITS PLANTS

IN our long journey from the dawn of plant life to the present, we have now come to what may be called the last lap, that is, the consideration of the plants of the Pleistocene or Great Ice Age, which just preceded and more or less merges into the present. This Ice Age, or Glacial epoch, was most in evidence in the Northern Hemisphere, especially in northeastern North America and in northwestern Europe. In North America this vast ice sheet covered at one time or another an area of more than 2,000,000 square miles, extending from Labrador to central Alaska, thence southeastward to Montana, down the Mississippi Valley, including parts of Iowa, Nebraska, and Kansas, and thence up the Ohio Valley to West Virginia, and touched the Atlantic in northern New Jersey. There were other smaller, more or less independent areas outside the above limits, especially on the Pacific Coast.

Although there were these vast areas covered by the ice, it is interesting to find that there were considerable scattered areas that escaped, such as the lands about the pole, northern Greenland, isolated spots on the Scandinavian Peninsula, western England, and most of Ireland, and, in North America, portions of Canada and Newfoundland, Wisconsin and Alaska. In the areas north of the continental glaciers of America many of the Arctic plants persisted, and this explains the interesting fact that the flora centering about the Gulf of St. Lawrence is more closely related to that of the Rocky Mountains and the Pacific slope than it is to that of eastern North America.

The thickness of the great ice sheet is not certainly known, and although there is evidence that in some places it was more than four thousand feet thick, it seems probable that the average thickness was much less than this.

The ice sheet was not uniformly present throughout the whole of the Ice Age, for there were times, perhaps as many as four

times, when the front of the ice retreated far to the north, and there were long intervals during which the climate was milder even than it is now. During one of these interglacial times some of the plants, such as the maple, osage orange, and sycamore, were able to spread more than one hundred and fifty miles farther to the north than they have gone since the last time the ice sheet covered parts of the country.

Then another turn of the wheel brought the ice back, perhaps farther toward the south than before, all of which brings up an interesting speculation: Did the last retreat of the ice mark the definite close of the Ice Age, or are we of today living in what may be only another interglacial interval?

The effect of this great sheet of ice was, of course, very profound on the plants and animals in the region over which it passed. As the animals could for the most part move about more or less freely, they were simply pushed further and further south by the slowly advancing ice and were largely able to escape destruction. Thus bones of the musk ox have been found in Louisiana some eight hundred miles south of the southernmost edge of the ice front, and more than two thousand miles south of their present and probable former home in the frozen north. As the ice front melted and moved back northward, the animals followed along and so soon regained their old homes, except such as happened to be stranded here and there in the south, and these by going up the mountains found a climate to their liking, and are now separated by hundreds of miles from their kin in the north.

The effect on the plant life was much the same, although sometimes it was more drastic. If the advance of the ice front was sufficiently slow, the plants were able to migrate slowly southward, but otherwise many were overwhelmed. The distance beyond the ice front to which lowered temperatures extended is not known, though it was probably less than many have supposed. In Alaska at the present time small glaciers come down to sea level in the midst of vigorous forests with very little effect on the surrounding vegetation, and in the Alps ice streams descend the valleys among the wheat fields before they finally melt. But the effect of these small bodies of ice may be quite different from that of a thousand miles of ice front. The last retreat of the ice also

left many plants stranded on southern mountain tops together with the animals just mentioned.

Our knowledge of the Pleistocene flora of North America is still very incomplete, due largely to the fact that the material, although known to be abundant in many places, has been very little collected and studied. The plant material that has been preserved consists largely of seeds, nuts, nutlets, cones, and fruits of various kinds, with twigs, branches, and sometimes trunks of trees, and rather rarely of leaves that happened to have been entombed in beds of clay. Occasionally more or less perfect leaves may be removed from the mass of vegetable débris, and preserved between pieces of glass, for if left to dry out they usually crumble to dust.

The preparation of this material, especially the seeds and the like, in a form satisfactory for study is often a tiresome and time-consuming process. Much of it is found in matted masses of partially decayed plant remains, such as are found in swamps or bogs, which must be pulled apart, and washed or strained or sifted repeatedly, and the minute seeds picked out one at a time under a magnifying glass, so that after hours of work the result may be only a dozen or so of tiny seeds. Then there is another and very real difficulty in properly identifying the seeds or nutlets after they have been isolated. This requires a wide knowledge of seeds and seed-bearing organs, and if possible, access to a good carpological collection. The prospective student of Pleistocene plants had best begin at once the accumulation of a collection of seeds, even of the commonest plants, for it is surprising how little they are understood, even by botanists. A fresh grape, holly berry, June berry, bittersweet fruit, wild crabapple, or the like, would of course be recognized instantly, but when the soft parts have disappeared, leaving only the hard seeds and nutlets, they present many a puzzling subject. However, it is a fascinating study, and well worth undertaking, for here is a great field practically unexplored.

Thus far only about two hundred and fifty species of Pleistocene plants have been identified in all North America, though it is well known that probably over ninety per cent of the plants now living in the region covered by the ice were in existence during the whole of Pleistocene time. Less than twenty of these

two hundred and fifty species are supposed to be extinct, but as several of these are represented by a single, often fragmentary specimen, and as all are obviously very closely related to living species, it is more than probable that when more and better preserved specimens are found the number of supposed extinct forms will be reduced rather than increased. As there are approximately four thousand species of flowering plants alone now living in northeastern North America, largely within the area formerly covered by the ice, it is obvious that the known Pleistocene floras are undoubtedly a very incomplete representation of the plants of the time.

The largest North American Pleistocene flora thus far made known is found in the Don Valley in the vicinity of Toronto, Canada. It comprises about eighty species, only one of which is regarded as being extinct. This is a large-leaved maple, quite unlike any American species, but most resembling the Norway maple of western Europe.

These Canadian deposits indicate that there were three more or less distinct climatic phases, the lower representing a warm, probably interglacial, interval, when the temperature was similar to that of the middle United States at the present day, as determined by the presence of the osage orange, juniper, southern white cedar, post oak, papaw, and blue ash. This was followed in the Don Valley by a cooler climate, similar to that of northern Quebec and Labrador, with such trees as the balsam fir and tamarac. There was also another interval intermediate in character, where a mild temperature prevailed during which the plants were similar to those now living in the region.

Two small distinct Pleistocene floras have been recognized in southern Maryland. The older, known as the Sunderland flora, includes twenty-two species, all of which are regarded as extinct, though several are extremely close to plants still living in the vicinity. This flora includes a sequoia, a maple, the woolly buckthorn (*Bumelia*), hackberry (*Celtis*), beech, hickory, walnut, sycamore, poplar, oaks, soapberry (*Sapindus*) and two elms.

Somewhat later was the Talbot flora of only seventeen species, all living in the vicinity at the present day, such as alder, American beech, black walnut, three pines, the cow or basket oak,

locust tree, elms, blueberry, and two grapes not specifically identified.

There are a good many points scattered over the United States, principally in the eastern and southern states, where Pleistocene plants have been found, but so few—usually less than a dozen—species occur at any one locality, that it is impossible to draw any very definite conclusions as to the climatic conditions, or indeed their exact position within the range of the Ice Age. However, they do often show a different or more extended range than now enjoyed, such as the finding of the bald cypress in New Jersey, far north of its present range, or Arctic willows and birches along the ice front as far south as latitude 40°.

The Pleistocene floras of Europe are far better known, and some hundreds of species have been recovered, largely in connection with the economic study of peat bogs, which fuel resource has been far more extensively exploited than in America. Doubtless in the fullness of time, when our supplies of coal approach exhaustion, attention will perforce be directed to our peat supplies and this will lead to a more critical study of the plants entering into it.

Pleistocene plants have been discovered at a number of localities in England, and some two hundred species have been found, giving evidence of at least three alternating and more or less distinct climatic phases. One found near the town of Hoxne on the northern border of Suffolk, is distinctly Arctic in character, with such plants as the Arctic willow (*Salix polaris*), and dwarf birth (*Betula nana*), which corresponds in some respects to the flora of Iceland. It is interesting to note that this bed containing the Arctic flora is associated with or immediately underlying a layer containing many Paleolithic implements.

On the west coast of Sussex there are several localities which together have yielded over fifty species, among them such as the English oak (*Quercus robur*), cornel (*Cornus sanguinea*), elder (*Sambucus nigra*), wild cherry (*Prunus padus*), and hazel (*Corylus avellana*). All the species found are still living in England, indicating that the climatic conditions must have been similar to those now prevailing.

More recently a flora of some seventy species has been recovered in the Lea Valley, indicating an Arctic assemblage, with

Arctic willows of several species, the dwarf birch, rue (*Thalictrum alpinum*), a common Arctic and Alpine plant, several northern buttercups, northern dock (*Oxyria digyna*), etc. Two species are regarded as extinct, a catchfly (*Silene*) and a flax (*Linum*), which appears to be most closely related to the common cultivated flax, and possibly its ancestor, as the wild original is not known.

Many localities for Pleistocene plants have been found in Scandinavia, especially Sweden, and in Germany and elsewhere, but we must pass them by.

Chapter XV

THE INFLUENCE OF MAN ON PLANT DISTRIBUTION

IN tracing the ages-long pathway plants have travelled, we have recorded only the natural agencies, largely climatic, that have influenced and determined their distribution over the earth. Now we may briefly consider what can perhaps appropriately be called certain "unnatural" agencies, which in the recent past have exercised and are still exercising a profound influence on plant life, namely, the part man has taken directly or indirectly in determining the distribution and extinction of plants. Man is undoubtedly the most destructive agent with which plants and animals have to contend. In a thousand ways his activities and his influences have reached out.

When we consider the plants that man has adapted to his needs, either as food for himself or his domesticated animals, for the making of his clothing, for the building of his habitations and for other uses, it is to be expected that they would be carried far and wide over the earth. Of course all cultivated plants once existed somewhere in a wild state, but many of them have been cultivated so long, and often so profoundly modified, that it is not possible to recognize the ancestral stock from which they came, or even the country of their origin. For instance, wheat, one of man's most valuable food grains, has been under cultivation for thousands of years, and is now grown in suitable areas quite around the world, with many local races adapted to fit varying conditions of soil, temperature or moisture. Similar conditions apply in greater or lesser degree to other cultivated plants.

In the process of preparing the soil for the cultivation of man's essential crops, the native plants have been swept away from millions upon millions of acres, and doubtless many of these plants have been actually exterminated. This work has involved not only the clearing of more or less heavily timbered regions, but especially the breaking up of vast areas of prairie and plain.

Irrigation enterprises, most of them undertaken in arid regions, have likewise displaced many native plants; and grazing, or rather over-grazing, by domestic herds has also played its part.

At the same time this displacement of indigenous floras has been going on all over the world, other far less desirable plants have been brought in to take their places and to dispute the possession of the soil with the cultivated crops. In the United States about eighty per cent of the so-called weeds of cultivation are not native plants at all, but have come from other parts of the globe. In an undisturbed region there is usually a long established "balance of nature," as it is called, whereby the spread of some plants may be more or less held in check by the successful competition of their neighbors, but if this balance is upset, by the removal of competition, they may spread like wildfire, especially when transported to another country. Here, under perhaps slightly different climatic conditions, and a rich soil, loosened and made ready for cultivation, ideal conditions are offered for widespread distribution, which often is held in check only by continual tillage. Perhaps sooner or later a second balance of nature will be struck between the native and this immigrant flora; in fact there is some indication that this is actually taking place with a few species. In New England, forty years ago, the Canada thistle was a serious pest, lining highways and invading grain fields, but it has now practically disappeared. Unfortunately, however, most of these undesirables seem to have come to stay, and more are continually coming. Thus *Galinsoga parviflora*, a small composite, has been introduced in recent years from tropical America and is spreading rapidly in the eastern and southern United States. It is partial to door yards and gardens, where it smothers everything unless held severely in check by cultivation.

The manner in which these plants have been introduced into one country from another is usually accidental and unknown, though doubtless they have mostly come as impurities with seeds and grains of various kinds. Not a few have come where ballast from foreign ships has been unloaded, and others as impurities in wool, and other imports. A plant thus introduced may fail to attract attention until it is out of control. The plant known as the king devil (*Hieracium praealtum*) is an example. This European plant was found a few years ago in northern central New

York, where it has now become a very troublesome weed in the fields, meadows, and along roadsides.

The most conspicuous and devastating changes are undoubtedly those wrought on the forests of the world. When the early settlers came to North America, some three hundred years ago, they found the country largely covered with splendid forests of both hardwoods and conifers, and, with what then seemed commendable zeal, they at once set about removing these forests to make way for agriculture. As the supply seemed inexhaustible, the timber was burned simply to get it out of the way, but later, as the population grew, there came increased demand for its use, and now the United States is confronted by the fact that its splendid forests are practically gone, with the available commercial supply being found now mainly west of the Cascades, in Oregon, Washington, and in Alaska. The recent enormous increase in the use of wood pulp in the manufacture of paper has made another serious inroad on the rapidly diminishing supply of timber, already necessitating importations of wood and wood pulp from other countries. To add to this destructiveness, 30,000 forest fires annually help on the devastation, destroying not only virgin stands of timber, but young growth that might some day partially restore the loss, and in many instances burning up the humus, that has accumulated for centuries, and thus effectively preventing reforestation. Some attempt is being made at artificial reforestation, but the net result is that America is depleting its forests more than four times as fast as they are being grown.

America's story of forest destruction has been and is being more or less duplicated all over the world. China, once apparently well-timbered, is now practically treeless over vast areas, with little hope of effective restoration. Central and western Europe was fairly well timber-clad within historic times, but is now largely deforested, though one or two countries, thanks to an enlightened forest policy, have conserved and are to some extent restoring their forests.

Of course there are still great areas in Asia and in the tropics of both hemispheres that are as yet little affected by the hand of man, but who dare say that these lands are forever immune?

The proof of this possible danger is well brought out in an elaborate ecological study, published in 1925, covering a large

area in the western Himalayas. This area extended from the tropical monsoon forest to the higher mountain summits. It supports a dense human population, with the usual resulting disturbance of the native flora. In the lower altitudes there remains a relatively scant development of the natural plant associations. The original vegetation is almost destroyed by man, following which still more disastrous effects are brought about by erosion. The forests have been completely destroyed over considerable areas through logging operations, and this, followed by severe erosion and burning of the dead vegetation during the dry spring, prevents reforestation. "These destructive human activities have been taking place for a long time, and seem to be getting worse rather than better."

The removal of the forest cover has brought about other changes on the face of nature. So long as the ridges and hills and mountains are covered with forests, the rains and melting snows find their way slowly into the streams, thus conserving the supply of moisture; but when the trees are removed the waters rush down, and not only remove much of the rich top soil, but trench and gash the hillsides with gullies and ravines, leaving only barren and unproductive soil exposed, and often causing disastrous floods in the lower reaches of the streams. In the United States these conditions are well recognized, and are being corrected where possible by the creation of parks and forest reserves about the watersheds of the streams, this action tending to prevent the rapid "run off" of the surface waters.

There is still another way in which plants have been forced to play a losing game at the hands of man, and that is by the introduction of plant-eating animals from one part of the world to another. When, a few years ago, a number of rabbits were liberated on Lysan, a small, low island in the western Pacific, they multiplied to such an extent that they almost completely denuded the island of its scant vegetation, and incidentally caused the destruction of several species of small birds that subsisted on the plants or their insect visitors.

Wherever goats have been introduced and allowed to run wild on islands, serious disturbances to the native floras have resulted. St. Helena, well known as the prison home of Napoleon, is a good example. This mid-Atlantic island is about ten miles

long and eight miles wide, and when first visited some four hundred years ago, was covered with splendid forests, which extended from the water's edge to the mountain peaks. Goats were liberated on St. Helena in 1513, and by 1588 they numbered thousands, seriously threatening the forests, which were almost completely destroyed by 1810. Since then the island has become almost a barren waste, so far as the native flora is concerned, though many foreign weeds have been introduced.

Fungus diseases of plants are also often transported from one country to another, sometimes with devastating results. Note, for instance, the chestnut blight, introduced from Europe, which seems likely to cause the complete extermination of the chestnut tree over the whole of the eastern United States; or the white pine blister, brought in from western Europe on nursery stock, which threatens the destruction of the splendid white pine. It is said that nearly a hundred fungus diseases that attack plants of more or less economic importance have been brought into this country from outside within a relatively short time, and the number attacking the native flora will never be known.

A number of herbs, shrubs, and trees introduced from the Old World into America as ornamental plants in parks and grounds, have become so thoroughly acclimatized that they have escaped from cultivation and become nuisances—such as the tree of heaven (*Ailanthus*), and the Japanese honeysuckle, which has become a pest in many localities in the eastern and southern States. Some American plants have found their way abroad, such as the locust, now a common tree in parts of western Europe, and the cactus, now "wild" in the Holy Land. Another cactus (*Opuntia*), is now a wayside plant on the borders of Thibet, whence it had been carried a hundred years or more ago by the Jesuit fathers returning from Southern California, and it is so thoroughly established that it was thought to be a native by later visitors.

In the tropics of both the Old and the New World, the interchange of plants, apparently mainly by human—perhaps prehistoric—agencies, has been so general that it is no longer possible to fix their original home.

This account could of course be almost indefinitely extended, with additional illustrative examples, but perhaps enough has been given to indicate the profound and wide influence that man

has had in modifying and controlling plant distribution, with all its attendant and subsidiary evils, including climatic and physiographic changes. Some of this evil has been due to stupidity, much more to cupidity, and not a little to a spirit of mere wanton destructiveness. The facts therefore warrant the repetition of the opening thesis, namely: that man is the most destructive agent with which present-day floras have to contend.

Chapter XVI

THE PROBLEM OF ORGANIC EVOLUTION

IN seeking a rational explanation of the cause or causes of certain observed natural phenomena, all available facts that harmonize and point in a uniform direction are brought together, and, when formulated, constitute a hypothesis or a theory. If the facts later made known that should fit into and supplement the theory fail to do so, then the theory obviously requires to be modified, or perhaps abandoned altogether. If, on the other hand, all subsequent facts corroborate it, then that which was put forth originally as a tentative hypothesis may come to be widely accepted as a principle or law. But no matter how firmly a theory may seem to be established or how long it may be accepted it is always subject to change or modification on the presentation of facts to warrant it. The recent formulation of the so-called theory of relativity is an example.

It was approximately this line of reasoning that resulted in the formulation of a theory of organic evolution, half a century or more ago, which created wide interest, and in this half century countless thousands of corroborative facts have piled up so high that it no longer seems necessary to present proof of the essential *truth* of evolution. "The demonstration of evolution," says Osborn, "as a universal law of living nature is the great intellectual achievement of the nineteenth century." It is, then, an established fact, no longer seriously questioned by those competent to judge, the world over. But when its causes or the methods of its accomplishment are sought, differences of opinion have arisen, and this apparent disagreement between scientific men has often been seized upon by those who scout the truth of organic evolution as an indication that even scientists no longer accept it as a fundamental truth. Of course, nothing can be further from the fact than such an idea, for there are many phenomena that are known and accepted as true, that cannot yet be fully explained,—electricity, for example.

Accepting evolution as an essential established truth, the mind

naturally seeks the causes that have brought about this wonderful manifestation. We have a very considerable knowledge as to *how* plants and animals evolve, but when we try to explain *why* they evolve, we are still left in practical darkness. Experience teaches that there is no such thing as a "causeless cause," and so there must be an explanation even if we can not yet find it. For a century or more repeated attempts have been made to determine the cause of evolution, but on critical analysis none seems to meet the necessary requirements, and with Professor Osborn we may say: "It is best frankly to acknowledge that the chief causes of the orderly evolution of the germ are still entirely unknown." It seems not improbable that the key to this problem may lie within the domain of chemistry and physics, but hereafter, in this brief chapter, we may direct attention to some of the methods, processes, and results of evolution; as to its ultimate causes we must wait for further light.

The fundamental assumption for organic evolution is that every plant and animal species now living on the earth has been developed from an earlier ancestral form, and this in turn from one still older, and so on back through the ages. This implies that if the whole series for each line was available, it would form a practically continuous chain, but it rarely happens that the paleontologic record is sufficiently complete to show all the transitional steps, many of which may well have taken thousands of years, and, as will be considered later, it seems possible, not to say probable, that the rate of progress was not always uniform, but at times may have been accelerated by one cause or another.

In this connection it may be of interest to pass in review, perforce somewhat hastily, the beliefs and conclusions of some of the principal students and groups of workers, who have sought for a century and more for the key to this intricate and complicated problem of the origin of organic species. Although the germ of the concept of evolution may be traced back for thousands of years, almost to the dawn of human understanding, the facts available did not then permit its adequate formulation and interpretation.

We may appropriately begin with the work of Jean de Lamarck, a French naturalist (1744-1829), who wrote early in the nineteenth century. Lamarck held that all plants and animals

have been developed from an ancestral stock, this development having resulted by efforts made within the organism to adapt itself to changing conditions of environment, and by the inheritance of such changes. These views were somewhat modified a half century or more later, by a group of so-called Neo-Lamarckians, who "seek to explain evolution according to fundamental laws of growth, plus the inherited effects of use and disuse, and of environmental influences."

The world owes much to Charles Darwin for having established the essential truth of evolution. Although, as already pointed out, the concept is centuries old, he vitalized it by offering what at the time seemed an adequate explanation, supported by a vast array of laboriously accumulated facts. Descent with variation was the keynote of the explanation. It is well known that no two plants or animals are exactly alike. Their differences, some of them minute, others more marked, especially if profitable to the individual, are selected and perpetuated. "This preservation of favorable individual differences and variations, and the destruction of those which are injurious, I have called Natural Selection, or the Survival of the Fittest." (Darwin: *Origin of Species.*)

This postulate naturally carries with it the assumption of the inheritance of acquired characters—that is, it assumes that the differences and variations acquired during the growth of the individual are passed on to the offspring. "From the strong principle of inheritance, any selected variety will tend to propagate its new and modified form." (Darwin.) In order to account for the "mechanism" of inheritance, Darwin assumed the existence of extremely minute granules or bodies that originated in all parts of the body, and, circulating through the body, finally came to rest in the germ cells. These granules were supposed to be able to reproduce the kinds of cells from which they came, and in this way any variation in the form of the body would be transmitted to the offspring. This is known as the theory of pangenesis.

The Darwinian theory of the origin of organic species was published in 1859, and at first had a rather stormy career, but after a few years it came to be very widely, indeed almost universally, accepted. As time went on, however, and all phases of the subject came to be subjected to critical study and experimen-

tation, it gradually became apparent that it might possibly require some emendation.

The trend of evolutionary thought was greatly influenced during the closing years of the nineteenth century by the work of August Weismann, a German biologist. Weismann held that the germ or sex cells were entirely independent of, or fundamentally distinct from, the body cells, hence that no effect of the experience of the body could affect the germ cells. According to this theory, as soon as the body began to develop the body cells became specialized, and each could give rise only to a part of the body. As an extreme view it might be inferred that each could exist without the other, but this is obviously untrue, for the germ cells appear long after the body is well developed, even approaching maturity; in fact it is now admitted by some that each body cell is potentially a germ cell.

A further blow against Weismannism was delivered when it was found that the segmented eggs of certain animals, such as sea urchins, could be cut into as many as eight pieces, and yet each piece could give rise to a perfect embryo. It was further shown that "the arrangement of these cells could be entirely altered by pressure so that the cells which normally gave rise to the front or back were deflected to the sides, and yet that perfectly typical embryos were formed." (MacBride.)

The work of Gregor Mendel, first made generally known to the scientific world about 1900, has had a profound and far-reaching influence on current thought regarding these intricate problems, especially heredity. Mendel was an Augustinian monk, who conducted a series of experiments with common garden peas in the monastery gardens at Brunn, Austria. His work extended over a period of some ten years prior to the publication of his results in 1866, and although he is known to have been in correspondence with certain German botanists the significance of his results was not appreciated, and his work remained unknown and forgotten for thirty-five years, or for nearly twenty years after his death. His results are now formulated as Mendel's Law.

Mendel selected the garden pea for his experiments, as the flowers are normally self-fertile and yet are easily cross-fertilized by removing the stamens, which are in a compact bundle, and applying the desired pollen. He procured from seedsmen ordinary

commercial varieties, which he grew for two years in order to be sure they were true to type. Then he selected for crossing those showing contrasting characters, such as tall vs. short, smooth-seeded vs. wrinkled-seeded, smooth-podded vs. constricted-podded, etc. For the sake of clarity, let us suppose that he had twenty-five flowers of a tall form (six feet) fertilized with pollen from a short form (one foot), and that each of the flowers produced four seeds, then the first cross would have resulted in one hundred hybrid seeds. When these seeds were grown it was supposed that they would produce plants showing gradations in height between the parents, but they did nothing of the sort, for they proved to be *all* tall plants. In this case the character of "tallness" is what Mendel called the *dominant* character.

If the one hundred plants resulting from the first cross are self-fertilized, and each produces four seeds, there will result four hundred seeds, and when these are grown it is found that they have split on a definite mathematical basis, in the approximate proportion of 3 to 1. That is, there will be three hundred of the dominant (tall) form, and one hundred of the short form, called *recessives.* The latter will continue to breed true, producing only short plants, whereas of the three hundred dominants, only one hundred—on the average—will continue to "come true," and the others will again split up in the proportion of three dominants to one recessive.

This is the essential part of Mendel's law, which has been found equally applicable to animals as well as plants, and has completely revolutionized plant and animal breeding. Before this time crosses were made in a more or less haphazard manner, with little knowledge of what the results would be, but now the results can be predicted with almost as much certainty as are chemical reactions.

It is held by many that Mendelism is a theory of heredity rather than a theory of evolution, but even so it has undoubtedly exercised a very considerable influence on current evolutionary thought. For one thing it has stimulated experimentation, and has seemed to set a limit to the effectiveness of variation. Many have held that most of these variations fluctuate about a mean—that is they can go only a short distance in any one direction, and hence can not give rise to any new forms. "Such fluctuating varia-

tions appear to depend on some action of the environment, and not to indicate differences in the germ cells." (Scott.)

Also about 1900 there appeared the results of certain experimental studies that seemed to hold great promise as being the long-sought explanation of the origin of organic species. Hugo DeVries, a distinguished Dutch botanist, conducted a series of experiments with a plant known as Lamarck's evening primrose (*Oenothera lamarckiana*). When wild plants were transferred to the garden they showed, in the second generation, sudden marked, even spectacular, variations from the wild parent plant. These variations, called *mutations* by DeVries, seemed to show all the marks of actual new species that had suddenly sprung into existence, and in fact several of these "new" species were described and named as such.

This mutation theory, although not entirely new with DeVries, was given such a powerful impulse that it was widely acclaimed, especially in this country, and it soon had many followers and experimenters. The biologists in particular conducted many experimental studies with animal forms, especially with *Drosophila*, the so-called pomace fly, which was selected because its short life cycle permitted the study and comparison of many generations in a short space of time. Experiments were conducted by the botanists on the original plant used by DeVries as well as on other plants, and many interesting results were obtained, some of which appeared to confirm the original results, and others not.

Now, if it could be shown that in all cases the stocks experimented with were absolutely pure strains, without taint of hybrid origin, then the mutation theory of the origin of new forms would seemingly be set on a pretty firm basis of fact. But as time passed, suspicions appear to have grown into conviction, at least with many, that the stocks themselves were of mixed origin, and that the so-called mutations merely reflect their hybrid composition. Experiments made with stocks known to be of hybrid parentage are said to yield exactly the same results as those seen in the mutants of *Oenothera*, *Drosophila*, and others. In fact, some recent investigators hold that mutations are really of the nature of monstrosities, and that instead of indicating strength of constitution, they really indicate weakness and would have very little chance of perpetuation in nature. Thus it appears that the muta-

tion theory of the origin of species will have to take its place with other theories that have thus far failed of confirmation. In truth, however, it should be added that the theory still has many advocates, especially among the biologists, and it should, and undoubtedly will, be subjected to still further searching inquiry.

There are of course many other phases of this complicated problem of organic evolution that could, and perhaps should, be presented, but many of them are still largely in the speculative stage, and it is perhaps best to turn from these more or less theoretical conclusions to a hasty review of some of the obvious results of the evolutionary processes.

It is a fact of common knowledge, hardly needing to be emphasized, that the angiosperms, or so-called flowering plants, are the dominant plants in the living flora, outnumbering all others combined by nearly two to one. In the astonishingly short time that has elapsed since their appearance in force in the middle of the Cretaceous period, they have spread over practically the entire earth. They have been able to adapt themselves to almost every conceivable climatic and topographic environment, ranging from the heart of the tropics to within five or six degrees of the North Pole; from sea level to mountain summits 12,000 to 14,000 feet high, where a little buttercup actually burrows a hole through the ice to send up its delicate flower stalk; and from the steaming tropics, with an annual rainfall of five hundred inches or more, to burning deserts where rain may fall only at intervals of years. Some find a congenial home in meadows, marshes, and along the borders of lakes and ponds; others have waded boldly into the waters and now compete with the algae; and a few have even invaded the ocean. In the matter of size they range from the tiny floating duckweed (*Lemna*), scarcely a twelfth of an inch long, to the Australian eucalypt, which sends its column four hundred and fifty feet up into the air, and in length of life from the herb that completes its life cycle, from germination to seed, in a single summer, to others, like the baobab tree, that may survive for several thousand years. In habitat, foliage, flowers, and fruits, and in a thousand ways, the variety seems illimitable, each adapted to and fitting into its environment. The only group able to compete successfully with the angiosperms is the conifers, and

these to an extent mainly limited to the northern forest and higher mountains areas.

What are the peculiarities that have permitted the angiosperms to gain and hold their present dominant position? It seems that this condition has resulted primarily by their compact method of reproduction—that is, by the seed-producing habit. The production of seed was not new, for it had been attained by certain plants as early as Devonian time, but it had not before been brought to its present state of perfection.

It has been pointed out, in considering the ferns, lycopods, and calamites, which were dominant until late Paleozoic time, that their reproduction was a complicated process, involving a very close adjustment as regards moisture at the critical moment. Then, as the moisture apparently decreased, and, moreover, as the developing plantlet was without a store of food to carry it on until it could become self-supporting, most of these groups were forced to extinction, and only a few of the more hardy types were able to continue. In the angiosperms many of these problems are solved. The female organs are produced in a closed vessel, where they are protected from danger and are not dependent on a supply of free water, as are the ferns, the only critical point in the process of fertilization being that at which the presence of the pollen, the male fertilizing element, is essential. After fertilization is accomplished, the immature ovule ripens into the seed, which contains nourishment sufficient to maintain the growing plantlet until it can establish a connection with the soil. In other words, the object of the reproductive process is to insure the adequate production of offspring with the least possible expenditure of energy that is consistent with efficiency, and this is what the seed-bearing habit in the angiosperm has accomplished. No other plants except the conifers, and these only under certain conditions, are able to compete with them. The tendency of each plant is to spread as widely as possible, to people the earth with its kind, and no doubt many species could largely have accomplished this if it had not been for the introduction of controlling factors that hold the tendency in check.

In this connection Darwin has given some interesting figures on the productiveness of the spotted orchid (*Orchis maculata*), a small plant a foot in height, growing in the northern part of the

Old World. A careful estimate of the number of seeds in a single capsule gave 6,200, and as each plant may bear as many as thirty such capsules, the total production of a single plant would be 186,300. The possible rate of increase, allowing four hundred bad seeds to each capsule, would give 174,240 plants, or just enough to cover an acre of land allowing a space of six inches square for each plant. At the same rate of increase the grandchildren would cover many square miles, "and the great-grandchildren of a single plant would nearly clothe with one uniform green carpet the entire surface of the land throughout the globe." Astonishing as these figures are, they are insignificant as compared with those showing the seed production in certain tropical orchids. Thus the capsule of an *Acropera* contained 371,250 seeds, "and judging from the number of flowers, a single plant would sometimes yield about seventy-four millions of seeds." (Darwin.) Yet orchids are among the rarest of plants.

The viability of seeds—the length of time they can retain their vitality before germination—is another factor that has undoubtedly contributed to the success of the angiosperms. Although there are some seeds, such as those of the mangroves, that actually germinate before they leave the parent plants, and there are others, notably the willows and sorrels (*Oxalis*), that germinate within a few hours, or a few days at most, a vast majority of seeds retain their vitality under normal conditions for much longer periods, ranging from a few months, as from fall until spring, to many years. In stored grain, for example, wheat retains its power to germinate for eleven to sixteen years, barley from eight to ten years, oats from five to nine years, and rye and corn for at least five years. Some years ago an interesting test was made on seeds of known age up to one hundred and thirty-five years, that had lain in the herbarium of the Paris Museum of Natural History. Of the five hundred species tested, seven germinated after fifty years, and one, a senna (*Cassia*), a small leguminous plant, after eighty-seven years, and more than fifty species germinated after twenty-five years in the herbarium. However, the statement often repeated that the mummy wheat found in the Egyptian tombs is still capable of germination is absolutely without foundation.

All are familiar with the fact that plants not now growing in

a locality may suddenly spring up, as in a forest area in the northern states that is cleared and burned over, on which comes up the great willow-herb or fire-weed (*Chamaenerion angustifolium*), or land that has remained undisturbed for thirty to fifty years produces a crop of weeds, the seeds of which must have lain dormant all that time.

There are many factors, not all of which are fully understood, that influence the viability of seeds, such as dryness, possession of a seed coat impervious to moisture, freezing, absence of oxygen, presence of carbonic acid, etc.

We are greatly handicapped by lack of knowledge concerning the origin and earliest evolutionary history of the flowering plants, but from the fact that they first appear on opposite sides of the Atlantic, in beds of approximately the same age, it is inferred that they originated in the north, whence they were able to spread southward over the continents. In middle Cretaceous time, when the flowering plants first became evident, the great continental land masses were in general relatively low, and there was a widespread expansion of epicontinental seas, but in later Cretaceous time the land masses were again elevated, and the shallow seas pushed back. It is inferred that the climates were relatively mild, at least in middle latitudes, that moisture was abundant, and that the stage was set for the rapid evolutionary and aerial expansion of this new type of plant. Possessing a vigorous constitution, based on this more efficient method of reproduction, the flowering plants easily pushed aside, or into the background, the original occupants and embarked on their conquest of the earth.

With little effective opposition, they evidently underwent rapid development and adjustment, and long before the close of Cretaceous time most of the larger groups, as well as many of the genera now living, had been established and widely scattered. This continued through Tertiary time, as they surged back and forth over the earth in response to climatic and other factors, and as we see them today in dominant control, we can but marvel at the niceties of adjustment that have been established between the plants and their environment. Have these adjustments been brought about as a result in whole or in part by the impress of the environment?

We may pass in review a few of these multitudinous adjustments, beginning appropriately with the *Cacti*, which are so perfectly fitted to their desert home. Some cactuses possess leaves, but in most of them stems have taken over the functions of leaves, and are thickened and fleshy for the storage of water. Some of the stems are flattened and sit prone on the surface, some are globular, and some have smooth or fluted cylindrical trunks that stand erect. All are provided with clusters of spines, which may represent modified leaves, prolongations of the nature of stems, or merely outgrowths. These spines have been interpreted by some as a means of defense against ruminant animals, and by others as a device to prevent loss of water. Every precaution is taken to conserve the precious moisture, even the sap being so thick and mucilaginous as to retard evaporation.

Cactuses are exclusively American, but in the deserts of South Africa many species of *Euphorbia* (spurge) have so closely simulated the cactuses that it is almost impossible to separate the two when they are without flowers or fruits, though the juice of the euphorbias is a white viscid latex. Other natives of the South African deserts are the many species of so-called carrion flowers (*Staptelia*) belonging to the milkweed family, which have assumed the form and appearance of the cactuses. Here, then, are members of three wholly unrelated families of plants that have similar forms and functions that adapt them to life in a desert.

In what may be considered the normal or ideal condition, favorable to active growth, there is a rapid current of water through the plant from the roots to the leaves, from which the excess water is evaporated. If for any reason the roots are not able at all times to absorb water fast enough to compensate for the evaporation, then some reduction of transpiration must be brought about if the plant is long to survive. "These conditions occur in many places—in countries with long dry seasons when the water supply runs short, in Arctic and high mountain regions where everything favors transpiration and the coldness of the soil checks absorption, in sandy or rocky soils, upon sea shores or on salt steppes where the presence of salt renders absorption difficult, and also in winter when the soil is too cold for absorption." (Willis.) These environmental conditions have been successfully met by plants in a great variety of ways.

The life of a plant like those just considered depends on its power to conserve moisture, but in a great many plants it is sometimes necessary to eliminate an excess of water. When the supply of water of such plants is plentiful, as it is in the tropical rain forests, the transpiration during daylight may be sufficient to balance absorption, but at night the root pressure may force up an oversupply, and this escapes through special openings, known as water-pores. These openings are usually at the tips of the leaves, where, in early morning, little glistening drops of water, often mistaken for dew-drops, may be seen, as on blades of grass.

Other elaborate precautions against loss of moisture have been developed, not only by plants inhabitating arid or semi-arid regions, but by those in regions with strongly contrasting seasons, either of drought or of cold. Thus in some the foliage is cut up into tiny leaflets, which reduce the exposed surface; in others the leaves or leaflets are long and narrow, and may be rolled inward; in still others the leaves are reduced to minute scales, and their function taken over by flat expansions of the stem known as phylloclades. Some of these stand edgewise to the sun; and certain tropical *Leguminosae* have the power of turning their leaflets—that is, in the heat of midday they turn so as to stand slantwise or edgewise to the sun. There is often an adjustment of the stomata or breathing pores to reduce or control evaporation, such as reduction in number by being confined to special pits or set at the bottom of deep grooves or channels, or covered by a dense mat of wool-like hairs.

Even the capsules and seeds of many plants have acquired "habits" that permit their adjustment to the conditions under which they live. In wet countries the capsules remain closed to protect the seeds from injury, opening only in dry weather; but in arid regions the capsules remain closed during the dry period, and open only when wetted.

In a previous chapter attention was directed to the part plants have played in the evolution of insects, and now we may consider the part insects have played in the evolution of plants. Someone has said that nature abhors self-fertilization, and although some apparently successful plants are adapted to partial or complete self-fertilization, the majority have undoubtedly become so adapted as to insure cross-pollination.

There is reason to believe that in certain of the earlier families of flowering plants the pollen was—and still is—wind borne, but there were others that undoubtedly possessed veritable flowers that began to attract insects, which became the agents of their fertilization. From this point adaptations progressed and became more and more specialized to attract particular insects, until we have the bewildering array of mutual adjustments of the present time. The floral organs (calyx or corolla), or variously modified leaves (bracts) associated with the flowers, have become colored, often brightly so, to attract the attention of insects. To make a visit worth while to the insect, special supplies of food in the form of sweets have been developed. As a further lure scents of various kinds have been evolved, some scarcely perceptible to human beings, others delightfully fragrant, and still others vile smelling, exhaling for instance the odor of tainted meat, as in the common skunk cabbage, many aroids, the gigantic *Rafflesia* of Sumatra, and the carrion flower of Africa, all of which attract carrion flies.

In order that the nectar may not be too easy of access, many flowers have a tubular corolla, thus inviting the visits of only long-tongued insects. For instance, there is a curious orchid (*Angraecum*) living in Madagascar that has the nectar produced at the base of a slender spur nearly a foot in length. Wallace, who shares with Darwin the promulgation of the modern theory of evolution, predicted that a sphingid moth would be found with a tongue of the same length, and such moths have since been discovered and described. In some cases certain bees and wasps have learned to take a short cut to the supply of nectar by biting holes in the base of the corolla, and are thus without the necessity of forcing their way into its mouth, though a sufficient number to insure fertilization may still do so in the proper manner. In many of these tubular flowers the lower lip or segment of the corolla has been enlarged to afford a landing place for visiting insects. In a Central American orchid a "petal" that is normally uppermost, has been moved downward to make a suitable landing place.

The great advances in the evolution of insects and of brilliant flowers were contemporaneous. This is emphasized by the fact that wind-fertilized flowers are without bright colors, and in regions where insects are scarce, as in the oceanic islands, there

are very few bright flowers. Wallace tells us that in the Galapagos Islands, which have a tolerably luxuriant vegetation, there is not a single bee and only one small butterfly, and there is "hardly a conspicuous colored flower."

Flowers that open at night, such as the moonflower and the night-blooming cereus, are usually white or light-colored, and also have a strong scent to attract night-flying moths. A case of extreme specialization is shown in a yucca (*Yucca filamentosa*), which has white flowers fertilized by a small moth. The moth first collects a ball of pollen, then deposits her eggs in the capsule between the ovules, after which she pushes the ball of pollen into the grooves of the stigma. The plant is completely sterile without the moth.

The foregoing account of certain of the environmental adjustments in the present angiosperm flora has been given rather fully —more detailed perhaps, than was really necessary—to show the seeming perfection of this adjustment, and also to serve as a possible basis for the interpretation of past conditions. To what extent has the environment influenced these changes and adjustments?

There is every reason to suppose that the plants of the earliest land flora were in the end successfully adjusted to the environment. If our supposition of the process is correct, when the plants first left the water they were weak, flaccid, and unable to stand erect. In order to assume an upright position they depended on a thickened cortex, which was made to serve until a vascular system could be developed. So long as the plants remained in the water they drew their sustenance directly from the medium in which they floated and had no need for roots, but with their advent on the land they speedily developed these special organs, though the earliest known plant that evolved a vascular system (*Rhynia*) was destitute of both roots and leaves. Close relatives of *Rhynia* (*Psilophyton*, *Asteroxylon*) were supplied with roots or rootlets, as well as leaves or supposed leaf-like organs. At first they absorbed the necessary carbonic acid for their nutritive processes through the stems, but at an early day they developed stomata or breathing pores. The descendants of this group of early vascular plants (the *Psilophytales*) are not known, and they may have disappeared by the close of Devonian time.

There is evidence that in Middle and Upper Devonian time several of the great groups of land plants had been established, including the ferns, seed-ferns, primitive lycopods, and ancestral conifers, which suggests strongly that they were derived from different aquatic stocks, but there are differences of opinion on this point.

The early ferns (*Primofilices*) are known mainly from the structure of the stems and petioles, with very little knowledge as to the foliar organs. Their fruiting organs where known show them to be unlike modern groups, though they may have given rise to certain of those groups. In Upper Carboniferous and Permian time there was a large group of splendid tree-ferns (*Psaroneae*), the direct descendants of which are the tropical elephant ferns (*Marattiales*).

When the seed-ferns, which possessed fern-like foliage coupled with the seed-bearing habit, were first made known it was supposed that they had been derived from the true ferns, but the two lived side by side in Devonian time, and hence must have been evolved from a common ancestral stock which has not yet been found.

The lycopods developed from a small beginning in Devonian time into the splendid lepidodendrons and sigillarias of the later Paleozoic, but they gradually dwindled throughout the Mesozoic and they are represented in the present flora only by the humble lycopodiums and selaginellas; and the calamites—also dominant and of tree-like size during the later Paleozoic—have fallen to the little horsetails of today. The evolution of the gymnosperms is much more complicated, and grave differences of opinion have arisen regarding it. At least one branch (*Cordaites*), once dominant, has disappeared, and another (*Ginkgo*) is reduced to a single representative, but altogether they have come down through the ages in far better shape than have many of the other groups mentioned.

What are the conclusions that may be drawn as to the relations between these early plants and the conditions under which they grew? When the plants first left the water they were confronted by a serious engineering problem, that of assuming the erect position. This was overcome by the development of a vascular system, which has also been made to serve other purposes. Later,

when many had attained tree-like size, evidence of mechanical stress is shown by their buttressed bases, adventitious roots, and often huge horizontal roots or root-stocks, which assisted in holding them upright in the soft mud in which they evidently grew.

To many it seems a legitimate conclusion that during the earlier geologic ages the earth was largely cloud-covered. This does not mean that sunlight never penetrated to the earth's surface, but that it rarely did so. Professor S. P. Langley, late Secretary of the Smithsonian Institution, states that the earth is fifty-two per cent cloud-covered at the present time. Many of the plants that have survived to the present day are essentially shade-loving, as an inheritance from their remote ancestors. Since the sun has assumed control of terrestrial temperatures plants have become more and more light-demanders, and even yet they are able to utilize only a fraction of its theoretical efficiency. It is therefore unfair to compare them with the ancient plants in this respect. It has been shown that for some plants at least eleven-twelfths of the sunlight can be cut off before the vital processes are seriously impaired.

During Paleozoic and most of Mesozoic time there were no flowers, at least as gauged by the angiosperm "flower," nor were there insects, or reproductive organs adapted to the requirements of insect aid. There were insects to be sure, but they had the mouth parts adapted for biting rather than sucking, and they probably rarely visited the plants. Certain Carboniferous ferns or seed-ferns had the petioles and seed coats covered with stalked glands, but whether these secreted nectar, or were made use of by insects, is of course, unknown. The spores, some of which were all of one kind, and in other cases with the sexes separate, were evidently produced in great abundance, and were distributed by the wind.

The ancient floras reached their culmination during late Carboniferous time, when they formed great swamp forests, as luxuriant perhaps as those of our present-day tropics, though of course with far less diversity of kinds. The accumulation of débris from the forests made possible the widespread deposits of coal. Their practically worldwide distribution is taken as sufficient proof that the climatic conditions were relatively uniform over a vast period of time. Temperature barriers such as would

now inhibit distribution were then absent. The actual temperature requirements of these forests have been variously interpreted, though they are held by many to indicate tropical or sub-tropical conditions.

After this presentation of some of the multitudinous adjustments that undoubtedly exist between the plants and their environment—not only the plants of the past but those of the present—we might naturally ask if a rational explanation of them can be given. The Darwinian theory of variation and selection seemed to supply the key, but we are told that the Darwinian period is over, and that variations revolve about a mean, beyond which they can not go, and within which they are held "as rigid as iron." A reaction from this extreme view appears to be indicated by some recent students who seem prepared to admit that minute changes induced by the environment may sometimes transgress the rigid bounds of this mean, and, if isolated, give rise to a hereditary series. It is difficult, however, to see how this differs essentially from the Darwinian concept. The problem is more or less involved in a maze of speculation, and general agreement is apparently still far off. The facts, however, are evident.

To a certain degree the influence of environmental stimuli is admitted. They are obviously of two kinds, *external*, as applied to all factors outside the organism, and *internal*, as applied to cells, cell-contents, and organs inside the body. Some very remarkable results have been obtained along these lines, especially with various stimuli.

The effect of the use and disuse of organs must also be considered. It is well known that when an organ ceases to be of use in the economy of the organism, it becomes more or less atrophied, and it may even disappear entirely. Conversely, when an organ is brought into increased use, perhaps as the result of a change in food or habitat, it tends to increase in size, function, and often in complexity. Many botanists, zoologists, and especially vertebrate paleontologists, attach great importance to use and disuse as an evolutionary factor. This naturally involves the consideration of the vexed problem of the inheritance of acquired characters, and here again for many students there has been erected another barrier, for it is contended that no experience of the body in one generation can be passed on to the offspring in

the next generation. Mutation and saltation which at first held out promise to the student, have been weighed and measured and have fallen short of universal application. But the end-product has undoubtedly been progress—that is, evolution.

Paleontologists in particular are firm in their convictions that variations due to the impress of environment have been and are transmitted from one generation to the next, and they are able to offer what seems to them adequate evidence in support of their contention. They are of course perfectly well aware of the apparent barriers and inhibitions that have been erected by the biologists, but they have not been wholly convinced by them. Is it not possible, they ask, that the pendulum has been permitted to swing too far away from certain of the earlier concepts? This possibility is appreciated by some biologists. Professor E. W. MacBride, a distinguished English zoologist, in an address before the University of London, spoke as follows:

> We are, therefore, in a position to state that after the lapse of the first quarter of the twentieth century, the doctrine of Lamarck has been submitted to the crucial test of experiment and proved to be true. New evidence of the actual course of evolution is derived from three classes of facts, namely, those of systematic zoölogy (i.e., the mutual relations of varieties and species), those derived from a study of embryology, and, finally, those deduced from paleontology or the study of fossils; and systematists, paleontologists, and embryologists alike have been forced to the conclusion that the effects of habits must be inherited in order to account for the facts which they find in Nature. We are then justified in saying that habit, which is the reaction of the animal to its environment, has been the great factor in evolution, and the splitting of the original stock into divergent species has been due to different members of the same stock under the stress of different environments adopting different habits.

Still more recently another English student has expressed views in essential agreement with those just quoted. Dr. C. Tate Regan, in his presidential address before the Section of Zoology of the British Association for the Advancement of Science,[1] has presented some very cogent reasons for his belief in natural selection, use and disuse, and the inheritance of acquired characters. His data are drawn almost entirely from the fishes, in which group he is a well known authority. In summing up his conclusions he writes in part as follows:

[1] *Nature*, Vol. CXVI. September 12, 1925, p. 398.

Throughout, the evolution of fishes illustrates the same principles. Changes of structure have been intimately related to, and may even be said to have been determined by, changes of habits, and especially changes of food and of feeding habits. Evolution has been adaptive, but modifications of structure that were originally adaptive persist when they are so no longer; they become historical and the basis for further adaptive modifications. I am satisfied that these principles, which I have illustrated by examples from the group I have specially studied, have a general application.

Darwin's theory of evolution was that it had been accomplished mainly by natural selection, aided by the inherited effects of use and disuse. Whether that theory be permanent or not, it was put forward by a man pre-eminent for his wide knowledge and his great reasoning powers, who knew the facts that had to be explained and gave us a theory that explained them. The *Origin of Species* still remains the one book essential for the student of evolution.

You will have seen, then, that I am inclined to accept Darwin's theory as a whole, including both natural selection and the inherited effects of use and disuse, at any rate until some better explanation of the facts is forthcoming.

Many biologists have adopted Weismann's germplasm hypothesis so whole-heartedly that they seem to regard it as a final disproof of Lamarck's theory. But when we consider that in progressive evolution, as in the development of the individual, increasing complexity of structure and localisation of functions is accompanied by coordination of the activities of all the parts, that differentiation and integration go together and the organism remains a unit, the so-called "inheritance of acquired characters" seems no more unlikely in the most advanced Metazoa than in the simplest unicellular organisms; and in some of these it has been proved.

Chapter XVII

THE INFLUENCE OF PLANT LIFE ON ANIMAL EVOLUTION

PLANTS have been the stimulating and controlling factor in the evolution of animal life, since, in its last analysis, all food of all animals is supplied by plants. Of course many animals feed on other animals, and these again on still others, but shortly a point is reached where a group draws its food supply from plants, and hence if this plant food supply should fail, the whole dependent chain of animal life would fail.

As the earliest plants were presumably of minute size, and had no parts that might be preserved in the rocks, our knowledge of them is still very obscure. Our knowledge of the early forms of animal life is equally obscure. In the rocks of the Algonkian period, which contain the first definite forms of plants—namely, algae and bacteria—the first faint traces of animal life also appear in the form of tracks, trails, worm burrows, and possibly parts of the shelly covering of some crab-like animal, but they are not very satisfactory or convincing. In the succeeding Cambrian, Ordovician, and Silurian periods, however, animal life in the sea increased in an astonishing degree, both as regards individuals and types, some of which have come down to the present day with comparatively little essential change. The known plant life of these times was also confined to the sea, and consisted of algae or sea-weeds, and probably bacteria, and there is evidence to show that they became exceedingly abundant, and toward the end the algae had evidently become greatly diversified, with some of the modern groups already established. It was undoubtedly this abundant supply of plant food, ready at hand in the sea, that made possible this wonderful rise and development of animal life. Of course we do not know—indeed, can never know—the thousands of actions and readjustments that must have taken place during the hundreds of millions of years that passed, for the paleontologic record is only a fragment, but the net result points in part at least to what must have transpired.

The first land flora appeared, at least in force, in Devonian time, and new possibilities opened for the animal world, though it was but slowly taken advantage of. With a very minor exception the animal life of Devonian time was still confined to the sea where, undoubtedly, the algae were still abundant, some having reached gigantic size, with trunks three or four feet in diameter. (See *Nematophycus*, page 68.) There were fishes in abundance in both fresh and salt waters, but the bulk of the animals were invertebrates, such as corals, shellfish, starfishes, trilobites, and their kin.

As it will be quite impossible in this short chapter to consider more than a fraction of the animal groups, in an attempt to indicate the evolutionary impress of plant life, the following account will be confined to three important groups, namely: insects, birds, and mammals, including man.

The insects were undoubtedly derived from some group of marine animals, and it is held by some students that this ancestral stock was the trilobites, the great group of invertebrates that was so abundant and diversified in earlier Paleozoic time, but this view requires confirmation. Insects probably came into existence within a short time after the first land flora appeared, though there is no conclusive proof of their presence during Devonian and Lower Carboniferous time, but this again may be due to the incompleteness of the record. In any event, by Upper Carboniferous and Permian time insects had become abundant, with more than a thousand species known, and strangely enough they then reached the largest size ever attained within the class, with cockroaches four inches long, and dragon-flies with a spread of wings considerably over two feet.

Perhaps on account of harsher climatic conditions brought on during the Permo-Carboniferous glaciation, the insects appear to have suffered a setback in Triassic time, or at least very few fossil forms have been discovered, but during the Jurassic they again became abundant, with many modern groups represented, such as caddis flies, scorpion flies, dragon flies, beetles, cicadas, grasshoppers, locusts, ants, and termites.

Our knowledge of the insects of Cretaceous time is not so complete as could be wished though the class certainly carried on with ever-increasing diversity.

The insect world of today includes over 640,000 described species, with the reasonable probability that, when the whole number is known, it will reach, if not indeed exceed, a million species.[1] There are approximately ten times as many species of insects as there are other species of the higher terrestrial animals combined, and an average of not far from ten insects for each species of angiospermous plant. The present deserves to be designated the "Age of Insects," and more than once the prediction has been made that they may ultimately destroy civilization and reduce the world to a barren waste.

Although the class of insects had its beginning, and had already evolved many of the modern groups, long before the appearance of the angiosperms, it is beyond question that the coming in and rapid spread of this group of plants greatly stimulated the further evolutionary rise of the insects. There very soon came to be established a sort of mutualism or interdependence between them. Before the advent of the angiosperms there were no bright-colored flowers or insects especially adapted to assist in their fertilization. There were flowers of a sort, in which the pollen was produced in great quantities and distributed largely by the wind. The earlier types of angiospermous flowers were also destitute of bright-colored floral organs, and still depended largely on the wind for transporting the pollen, but by upper Cretaceous and Tertiary time, types had been developed that undoubtedly had bright-hued flowers that attracted insect visitors. Many of these plants came more and more to depend on outside, mainly insect, assistance in the fertilization of their flowers, and not a few evolved to the point where they are not only absolutely incapable of self-fertilization, but must rely on a particular kind of insect. Examples of this kind are offered by many orchids. Their flowers are so arranged that the pollen grains are held together in a compact club-shaped mass that must be removed forcibly from the modified stamen by sticking to the head of a visiting insect, and when the insect visits another flower the pollen mass is in the exact position to be brought in contact with the stigma. The whole process of orchid fertilization is charmingly told by Darwin in his book *The Fertilization of Orchids by Insects.*

[1] Since the above was written Mr. S. A. Rohwer, of the United States Bureau of Entomology, has expressed the opinion that there may be more than five million species of insects.

The commercial fig furnishes another example. The minute flowers of the fig line the inside of a closed receptacle or hollow flower-stalk, which ripens into what seems to be a sort of berry. It is incapable of self-fertilization, but a small wasp, forcing its way into the receptacle, accomplishes the fertilization as it crawls about the walls in securing its food. When the fig was introduced into California and Arizona from its home in northern Africa, it failed to mature fruit until the wasp was introduced and liberated in the fig orchards. Neither apparently can thrive without the other.

The second of the three groups of animals selected for review in this chapter includes the birds. Unlike as they may seem at the present time, birds are closest akin to the reptiles; in fact it is beyond question that they had a remote common ancestor. The oldest bird thus far known is found in the Jurassic rocks of Bavaria. It was about the size of our common crow, but in addition to typically bird-like feet it had a long, slender tail like that of a lizard, which bore some twenty or more pairs of tail feathers along its sides, and jaws with sharp teeth; thus indicating its reptilian relationship. The shape of the teeth would indicate that it subsisted on animal food of some kind.

A further step in the evolution of the group is shown by some interesting remains found in the Cretaceous chalk beds of western Kansas. Although considerable progress had been made toward modern birds, they still possessed reptilian teeth, an indication that their food was animal, probably fishes.

The toothed birds dropped out, and the modern types came on the scene. Fossil remains of birds are always rare, so the complete story cannot be written, but in early Tertiary time such remains as have been recovered belong, all or nearly all, within living groups, showing that they must have originated well back in the Cretaceous. In later Tertiary time practically all belong to living genera, and it seems safe to assume that their food habits were similar to those of their living descendants. Although some living birds subsist largely on the seeds of conifers, and some on aquatic life of various kinds, the vast majority feed directly on the seeds, fruits, nuts, and buds of angiospermous plants, or indirectly on the insects that in turn feed largely on these plants, thus indicating the evolutionary impress of this group of plants.

We may now consider briefly the influence of plant life on the marvellous rise and development of the mammals, the animals that suckle their young, now the dominant group. As happens in so many cases, knowledge of the actual beginning of the group is more or less obscure. The earliest forms, so far as we now know, are found in rocks of Triassic age. They are thought to be some of the ancestral forms of the living group of marsupials, that is, mammals like the opossums and their kin, in which the young are born very immature and are transferred to an external pouch, called a marsupium, where their development is completed. They were small animals, not much larger than mice. It is impossible to interpret their food habits with certainty, though it seems most probable that they were either flesh- or insect-eating, nor is it possible to determine whether they possessed a marsupium, though it is thought probable that this may have been a feature of later development.

Very little is known regarding the evolutionary steps followed by the mammals during Jurassic and Cretaceous time, but again this is undoubtedly due to the imperfection of the geologic record, for no sooner is the Tertiary entered than there seems suddenly to have sprung into existence such a multiplicity of forms, showing such differences in structure, many of them indeed already highly specialized, as to point unmistakably to the conclusion that they must have had a long earlier period of development. It has been the tendency to presume that many of the modern groups of mammals were derived from certain known and seemingly archaic early Tertiary types because these happen to be the oldest forms recovered, but later studies have shown that we must look much further back for actual starting points of many forms. The great group of rodents furnishes an example in point, and there are doubtless many others. It has been shown by Doctors Gidley and Miller, of the United States National Museum, that at least two of the four great divergent lines of rodents could not possibly have been derived from any known Tertiary ancestors, but must have originated well back in the Cretaceous. Of course there is no assurance that these Cretaceous forerunners will ever be discovered, but the hope that they may be found is the constant spur to exploration. It is thought by many that the

great continent of Asia may hold the key to much of this ancestral mammalian history.

It will be seen, by referring to Chapter X, that this rise and spread of the mammals is practically coincident with the rise and spread of the angiosperms, or flowering plants. Up to early Cretaceous time the land vegetation consisted almost entirely of ferns, fern-like plants, lycopods, cycads, and conifers, a type of vegetation unsuited to the needs of mammalian life. Much of it is harsh, unnutritious, and some of it even poisonous, at least to modern mammals, so it is safe to say that if this type of plant life had continued, there would have been but a few if any important mammal groups developed.

Early in Upper Cretaceous time the great group of grasses was evolved, and although our knowledge of the early forms of grasses is not as complete as could be wished, as they are not well fitted to be preserved as fossils, it is reasonably certain that they very soon spread widely over the uplands and open spaces. The grasses, and especially their seeds, are very nutritious, and they thus furnished the setting for the rise and spread of the herbivorous mammals, and, as already pointed out, by early Tertiary time many of the great groups of this type had not only become well established, but already showed a high state of specialization or adaptation to particular modes of life, while other groups continued with various modifications through the Tertiary to the present time.

The evolution and world-wide distribution of the herbaceous and seed-eating mammals in turn stimulated and made possible the evolution and spread of the carnivorous or flesh-eating groups of mammals, all, in last analysis, depending on the presence of the angiosperms.

It would be interesting, if space permitted, to follow the evolutionary history of many of these groups of mammals as they have come on down to the present, and especially their geographic distribution, as they have surged back and forth over the earth, but, perforce, this is a story that must be told elsewhere.

It of course goes without saying that man falls within the great group or class of mammals, and, as we shall see later, the factors that combined to make possible the evolution of the class in general apply with almost equal force to human evolution.

The geographic location of the so-called cradle of the human race is still a moot question, though, from the facts now available, it seems most probable that it was somewhere in tropical Asia. Likewise, the geologic date of man's appearance, or perhaps better the appearance of his more or less man-like ancestors, is also somewhat uncertain, though from facts at hand it must have been as early as Pliocene time, or probably not far from five hundred thousand years ago. The group of Primates, the highest group of the mammals (at least so far as regards brain capacity), to which man also belongs, had its origin far back in geologic time, in the earlier part of the Tertiary period. At first they were crude, and the Primate characters obscure and hardly recognizable, but gradually they took form, and came more and more to embody the characters of the living group. Finally, at a point not certainly determined, two lines of the Primate stock began to diverge from a common ancestral form, one line of which culminates in the higher apes and their close relatives, and the other in man.

When man began first to emerge from the bonds of darkness he must have found himself in the presence of a bountiful Nature, to which he turned for subsistence. He must have depended principally on such seeds, nuts, fruits, roots, and succulent herbs, as well as various animal forms, as he could readily procure. That this must have been the case is shown by the fact that there are tribes living today that have advanced but little beyond this primitive state of culture.

Doubtless thousands, or more likely tens of thousands, of years passed before there was much improvement in man's condition beyond dependence on the natural bounty of Nature, but sooner or later he came to realize that the food supply could be more easily and regularly procured when the plants and animals he had found most useful and desirable were cared for, cultivated, or protected from their enemies, and thus agriculture and husbandry were born.

Time passed, slowly perhaps, but gradually man came more and more to adapt the plants and animals to his real or fancied needs, and to assume his present dominant position, with the whole world laid tribute.

With minor, practically negligible exceptions, the entire plant

food of man and his most important domesticated animals is supplied by the angiosperms or so-called flowering plants, and thus again is emphasized the outstanding importance of this great group of plants.

Chapter XVIII

VALUE OF THE STUDY OF FOSSIL PLANTS

WHAT is the value of the study of fossil plants? This question is almost certain to be asked, and a proper reply should point out the fields in both botany and geology in which the study is of undoubtedly great and permanent value. If it were undertaken merely to obtain pictures of the many strange floras of the past and to trace or to attempt to trace their gradual evolution into the floras of the present the study of fossil plants would be well worth while; but it is of far wider usefulness.

Paleobotany, as well as paleozoology, may be divided into two kinds of study, the biological and the geological. The biological study of fossil plants is devoted to identifying them and placing them as nearly as possible in their proper botanical (biological) positions—that is, to determining their kinship and to interpreting the story that each plant has to tell regarding its position in the evolutionary chain. The interpretation made is based largely on our knowledge of living floras. The plants that lived in the later geologic periods are naturally most closely related to those that are now living, and ordinarily they are not difficult to place; but as we go further back in time the difficulty of placing them increases, as does also their interest and their significance.

It is largely the results of the biological study of fossil plants that have been presented in the preceding pages. Of course there are still many gaps in our knowledge of the lines of development, but the record of the work done each year shows additions, and a review of the progress made during the last few decades discloses striking advances. This wide field is open to the student, and the reward of his study is practically certain. A vast amount of material in which the internal structure is preserved is now awaiting study. This material includes wood from many localities and horizons, Paleozoic coal balls that may throw light on the vexatious question on the origin of the flowering plants, and numerous stems, cones, seeds, and flowers. Improvement in technique has made it possible to learn much regarding the plants that formed

coal, both anthracite and bituminous, and improvement in methods of studying the cuticle of fossil plants has afforded better facilities for recognizing more certainly the affinities of plants that were previously known only from impressions. As has already been stated, a wide field is still open for the student of the Pleistocene flora, the remains of which include impressions of leaves, fruits, and seeds, as well as specimens of woods, stems, and seeds showing internal structure.

Turning now to the geological application of paleobotany we may begin by saying that it is in this field that the study of fossil plants makes its strongest utilitarian appeal. The sedimentary rocks, which are practically the only rocks that contain fossils, have been divided by geologists into a number of major divisions, and these again into smaller and again into still smaller divisions. It was at first not thought necessary to use divisions smaller than those representing what are called epochs, but it is now thought necessary to define what are known as formations, which are the smallest units generally recognized by geologists. Technically speaking, a formation is defined as a "mappable lithologic unit" —that is, it is a bed or layer of rock, or a series of layers, that is sufficiently distinct lithologically from those below and above, and sufficiently large in extent, to permit its representation on an areal map by a separate color or other distinctive convention.

The greater part of the work of the geologist consists of identifying and describing formations, tracing them from place to place, and putting each into its proper position in the time scale or geologic column. Formerly the mineral composition and lithologic character of a formation were most relied upon in this work, and they are still significant and valuable, but the organic remains found in a formation are now regarded as unquestionably of greatest value in determining its age, or its stratigraphic place. "We regard fossils," says Professor J. W. Judd, "as the 'medals of creation,' and certain types of life we take to be as truly characteristic of definite periods as the coins which bear the image and superscription of a Roman emperor or of a Saxon king."

This use of fossils is called stratigraphic paleontology, in which the study and identification of fossil plants play a part coordinate with the study and identification of fossil animals. Few if any beds of marine origin contain fossil plants, but in fresh-water

beds plants may be the only or nearly the only fossils found. Some types of plants are geologically long-lived; they persist from one geologic period to another, though with more or less modification, and some pass more than one line of division, but the greater number of certain types are confined to a single major division, and many are confined strictly to the smallest recognized geologic unit—the formation. Such fossil plants therefore become marks of identification—horizon markers, as they are called—and as such they enable the geologist to identify time divisions—to determine with reasonable certainty the age of the rocks he is studying and to carry the identifications from one region to another.

Some formations contain large numbers of certain fossil plants, which form distinctive floras, each different from the flora of any other formation and therefore serving as a means of identifying, from place to place, the formation in which it is found, and also, by means of the larger study of fossil plants, a means of determining its stratigraphic horizon or geologic age.

The fossils found in some formations consist mostly of the remains of plants, which are so numerous and yet so closely restricted to certain types as to form distinctive floras, by which the ages or the stratigraphic positions of the formations containing them may be determined, and by which any such formation can be traced from place to place with certainty.

The formation called the Dakota sandstone is an excellent example. This formation is four hundred to five hundred miles wide, is more than one thousand miles long, and is of considerable thickness. According to Leo Lesquereux, the Nestor of American paleobotany, some 460 species of plants found in this formation have been described, of which number no less than 394 are peculiar to it—they have not yet been found outside of it. A large number of these plants are so distinctly characteristic of the Dakota formation that their discovery in beds of unknown age would fix at once the geologic age of those beds. These plants form what is called the Dakota flora.

The ages of hundreds of other plant-bearing formations are similarly determined; each contains many, even hundreds, of characteristic species—species peculiar to that formation. It is obvious that these horizon markers are of great assistance in

identifying geologic horizons, and in this field of study there is ample opportunity for additional workers.

Fossil plants are thus used in identifying horizons at which deposits of commercial value are found, such as coal beds, oil-bearing shales, beds that are likely to yield underground water, and the like. Plant-bearing layers are especially likely to lie just above or just below coal beds or in rock partings in coal; and in prospecting for a valuable bed of coal the discovery of certain species of plants above or below a bed indicates that it is the bed sought. Many valuable beds of coal have been found in this way—beds that might otherwise have long remained undiscovered.

The use of fossil plants to determine climate is another of the many aids of paleontology to geology. "They are," says Asa Gray, "the thermometers of the ages, by which climatic extremes and climate in general through long periods are best measured."

Chapter XIX

COAL AND ITS FORMATION

OF course everyone is familiar with the appearance and the modern uses of coal, and probably nearly every one knows in a more or less vague way that coal has been produced from plants. It is proposed in the following pages to explain the manner in which the vegetation of the past has been changed into the coal of various kinds as we now find it buried in the earth.

The story of coal reads like an absorbing romance, not only as to the manner in which it was formed but also and more particularly as to the part it has played in the advance of civilization. "Coal," says Dr. J. S. Newberry, "is entitled to be considered the mainspring of our civilization. Wealth with its comforts, the luxuries and triumphs it brings are its gifts, and its possession is therefore the highest boon that can be craved by a community or nation." It is perhaps hardly necessary to reaffirm the truth of this statement, for it is a matter of common knowledge that those nations possessing, or having easy access to, supplies of coal have enjoyed the greatest prosperity; in fact the value of coal can hardly be overestimated.

The present spelling and meaning of the word "coal" is comparatively recent. It was originally spelled "cole" and it comes from the Anglo-Saxon word "col," or the Icelandic "kol," and was applied to any substance that could be used as fuel. It was usually combined with another word, such as "chardcole" (charcoal), which is wood that is burned in a closed vessel, or kiln, from which the air is shut out, so that the wood is "charred" but not entirely consumed. Later, when wood became scarce, other sources for fuel were found in the coal as we know it, and to distinguish it from "charcole" it was called "earthcole," "stonecole" or "pitcole" and sometimes in England "watercole," because it was often brought to London by water. Finally, as the earth fuel became more common, the first part of the word dropped out of use, the spelling was changed, and so in the end we have "coal."

Perhaps the first mention in literature of what must have been

coal is found in a work by Theophrastus, a celebrated Greek philosopher, written about 315 B.C. He mentions a kind of earth that would burn and was used by blacksmiths in heating their metals. But its light was dim, and many centuries passed before it attracted much attention. In England coal is first mentioned in one of the Norman Chronicles in 853, and the first royal patent or charter for mining coal was signed by Henry III in 1239. But for nearly five hundred years thereafter the use of coal made very little progress. Coal was discovered on the Lehigh in Pennsylvania in 1792 and a company was formed to mine it, but the project was soon abandoned. Some of the coal, it is said, was tried under the boiler of the engine at Center Square in the first Philadelphia waterworks, but it served only to put the fire out, and the remainder was broken up and spread on the walks as gravel. "The black stones will not burn," everyone said. In 1812 two enterprising manufacturers of wire near Philadelphia, Messrs. Josiah White and Erskine Hazard, early appreciated that they needed a liberal supply of fuel that could not be supplied by wood or charcoal and so they procured a few tons of coal from Lehigh for trial. Their attempt to make it burn is described as follows in an account of the life of Josiah White: "Incredible as it may seem at this day, great difficulty was found in causing it to ignite, mainly from want of patience and from the deficient draft of the fireplace in which the effort was made to burn it. An entire night was spent in the vain attempt, when in despair the workmen shut the furnace door and retired and left the coal to its fate. Fortunately one of them had left his jacket in the mill, and on returning for it in half an hour, noticed that the door was red hot, and upon opening the furnace was surprised to find the mass at a glowing heat." The secret of kindling anthracite had been discovered.

For the next few years, however, the increase in the use of this new fuel was very small indeed. Thus in 1820, only 365 tons were sent to market, but this was more than enough to supply the families who would use it. In 1823 about 5,800 tons were sent down the Lehigh, but nearly 1,000 tons were left unsold by the following spring. The use of coal was established, however, and just one hundred years later—in 1923—the production of anthracite in the United States reached 86,580,000 tons and that

of bituminous or soft coal the enormous total of 494,772,000 tons, while the world production of coal of all kinds for that year was 1,395,000,000 tons. In 1923 the railroads in the United States alone consumed approximately 150,000,000 tons.

Coal is often spoken of as mineral fuel, but as a matter of fact it is not a mineral but a *rock*, and moreover it is a sedimentary rock—that is, it was deposited under water as is sandstone, limestone, and clay. There is, however, a varying amount of mineral matter in all coal, a part of which came from the water in which the coal was deposited and a part from the plants themselves. Most of the mineral matter remains after the coal is burned and forms the so-called *ash*.

Of the two principal explanations that have been proposed to account for the manner in which the vegetable material was brought to the place where it was later changed into coal, the first is known as the transportation or flotation theory. This supposes that the plants did not accumulate in the places where they grew but have been floated from a greater or less distance by water, perhaps into a quiet pond or lake, and becoming water-logged, sank to the bottom, where the process of decay was more or less stopped and where they were finally changed to coal. This floated material was supposed to consist largely of the trunks and limbs of trees, but also of such other parts of plants as would naturally fall into the water, such as branches and twigs, leaves, fruits, seeds, spore-cases, spores, pollen grains, etc.

It is possible that in exceptional cases coal could have been produced in this manner, and in fact there are a few instances on record where this does seem to be the manner in which the vegetable matter was accumulated, but there are so many valid objections to this explanation that it is no longer considered tenable by those best able to judge. To mention only one of the objections: It is hard to imagine how conditions could have remained unchanged, and so nicely adjusted over areas of hundreds of square miles, for a sufficient length of time to permit the accumulation of transported vegetable material enough to have produced a bed of pure coal, several or many feet in thickness, without at the same time bringing in mud and sand. Every freshet, if it was strong enough to uproot and transport trees, would certainly have brought its load of mud and sand to be

deposited on the bottom of the pond or lake, covering up any layer of vegetable matter already there.

The other explanation, and the one now almost universally accepted, is known as that of growth in position (*in situ*), that is to say, that the plants lived and grew and died in the place where their remains were later changed into coal. It seems now settled beyond any reasonable question that a vast majority—perhaps ninety per cent—of the coal beds of all ages and in all places were formed in this manner, and the first steps in this process are going on in many parts of the world at the present day, though not of course on the same scale as at many times in the past.

It is now very generally recognized and accepted that coal is consolidated and more or less changed peat, and the first step in the formation of coal is naturally the formation and burial of peat of some kind.

Peat, peat bogs, or peat swamps are familiar terms to most people, but they need to be described and defined in order that the reader may have freshly in mind just what they mean. Peat, which may be called young coal, is the vegetable matter of many kinds that has accumulated in a swamp, a marsh, or other shallow depression constantly filled with water. It is well known that if the trunk of a tree is left exposed on the ground it is attacked at once by the agencies of decay, which include bacteria, fungi, insects, chemical action, etc., and in a very short time is reduced to powder. This is the way so-called humus or "soil" is formed. If, however, the same trunk had been constantly covered by water the processes of decay would have been slowed down or almost entirely stopped, and it would be in a position and condition to be preserved indefinitely or as long as these conditions were continued. This is the way the peat is formed. The plants of all kinds, that if exposed to the air would decay in a very short time, are more or less completely sealed by the water and the air shut out, so that they are very slowly broken down by decay. This process goes on year after year, with fresh plants growing at the top and contributing their roots, branches, leaves, fruits, seeds, etc., to form an additional layer on the top of the vegetable matter already there, but there must be a constant, never-failing supply of water. In this manner little by little the layer of peat is built up. The weight of the uppermost layers is constantly pressing

down and consolidating the lower portion. If these conditions continue for a very long time, with little or no change, a bed of peat may be built up that is many feet in thickness. Thus beds ten, twenty, or even thirty feet thick are not uncommon at the present time.

Beds of peat are being formed in many parts of the world at the present day. In the United States the places that seem most favorable for the formation of peat are in those northern States that were covered by the ice during the great Ice Age. The great ice sheet, as it moved over the surface, removed much of the loose surface material and left many shallow depressions, and in its final retreat it dumped its load of earth and stones, damming up valleys and producing innumerable little lakes and ponds. As the drainage was poor from these ponds the water level was held in a nearly constant position, and these ponds became favorable places for the formation of peat. However, peat can be and indeed is being formed in the warmer parts of the earth, as for example in Florida, in the great tropical rain-forests of Sumatra, and elsewhere, in fact anywhere, regardless of temperature, where there is an abundance of vegetation and a constant and copious supply of water. In Sumatra, for instance, there is a very heavy rainfall, which keeps the water of the great swamp constant and the air fairly steaming with moisture, all of which permits a very luxuriant, rapid-growing vegetation that never dries out, with the result that a bed of peat over thirty feet in thickness has been formed. But, taking all of the things into consideration which make the formation of peat possible, such as the surface of the earth, moisture, temperature, etc., the conditions are less favorable at the present time than they evidently were at many times in the past, at least on an extensive scale. This will be mentioned later.

We may now follow the various steps that are believed to have taken place between peat and the several kinds of coal commonly recognized.

When the upper layers of a bed of peat are examined it is found that the material is rather loosely compacted and can be easily pulled apart, and most of the plants or parts of plants that enter into its composition can be recognized. Although the processes of decay in the peat are slowed down they are not entirely stopped.

These processes consist of action by minute organisms, particularly bacteria, and certain quite complicated chemical changes. If these processes are not stopped for a long time it may result, in very old peat, in changing the plant material into a black structureless mass in which very little of the original plant structure can be found. It usually happens, however, that the action of the bacteria is cut short, either from lack of oxygen or by the poisons they have themselves produced, and the decay is stopped before the woods and other plant structures are completely destroyed. The peat is then brown in color.

The upper layers of a peat bed contain from eighty to ninety per cent of water, but by the time some eighteen or twenty feet of peat has accumulated, the slow processes of decay above mentioned have been going on, the mass of vegetable material has been reduced to about one-fourth of its original bulk by weight, and about forty per cent of the water has been lost by chemical action and by the pressure of the overlying mass of material. Much gas has also been given off during this part of the process.

The depth in a peat bed at which bacterial decay stops is not positively known, but below twenty feet it is greatly retarded if not entirely stopped. This condition may continue until a considerable thickness of the black, more or less structureless mass of peat has accumulated; then purely geological and chemical processes step in and continue the change into coal. If the basin or great swamp in which the peat was forming began to sink, the first effect would be the killing of the plants in the basin, and as the nearby rocks began to wear down, due to their increased elevation, quantities of clay, sand, and gravel would be poured into the basin and on top of the beds of peat. This filling up of the basin often continued until hundreds and even thousands of feet of material were piled up. This enormous weight served not only further to compress the peat but also the sand and mud, which was changed again to more or less solid rock. This compression squeezed out more and more of the water and the volatile matter—that is the gases of various kinds—and the point to which this progressed mark the different kinds of coal. Thus lignite or brown coal contains thirty per cent or more of water, bituminous (soft) coal contains less than ten per cent, and anthracite (hard coal) three per cent or less of water. The chemistry of coal and the

various stages between peat and mature coal is a very complicated and difficult study, and there is still much to be learned about it. It is found, for instance, that there is not only a marked difference between coals of different ages but between coals of the same age and even in different parts of the same bed. There is no such thing as a standard coal of any grade, though for commercial reasons certain more or less arbitrary standards have been adopted, depending upon their heating, coking, steaming or other uses.

There are of course many intermediate steps between the principal grades, such, for instance, as sub-bituminous coal, which is intermediate between the lignite and bituminous types. This coal, formerly called "black lignite," includes most of the fuels of the Western States; it is generally glossy black in color and contains more than ten per cent of moisture.

Perhaps a more extended description of lignite may be of interest, especially as it exists in vast quantities in many parts of the world, and is likely to be utilized in the not distant future, when the supply of higher grade coal nears exhaustion, not only as fuel, but as a source of oil. Lignite is a term applied to all brown coals, and may be roughly divided into two kinds, one known as xyloid (Greek *xylem*, meaning wood), and the other as amorphous lignite.

Xyloid coal, as its name implies, is made up almost entirely of wood, much of which can be seen by the naked eye, and not infrequently whole logs can be made out, matted and massed together. It is found mainly in beds of Cretaceous and Tertiary age, and occasionally in older rocks.

In amorphous lignite the wood element, though usually present, is much less conspicuous, with only occasional logs, branches and twigs. The processes of putrefaction have progressed to the point where the vegetable matter has been broken down into a more or less structureless mass, though with discernible traces of more resistant structures, such as cuticles, spore cases, spores, pollen grains, waxes, resin, etc.

All lignites, but particularly the amorphous type mentioned above, yield varying amounts of petroleum or so-called mineral oil, which is recovered by heating the coal in a retort for twenty-four hours at temperatures ranging between 400° and 1200° F., when the oil is driven off and condensed. The quantity of oil

recovered varies somewhat with different coals, but a fair average is perhaps from twenty-five to forty or fifty gallons per ton.

There is another great possible source for oil in the so-called oil shales, of which there are extensive deposits in many parts of the world, particularly in the Rocky Mountain region. This oil shale is a clayey or shaly deposit from which petroleum may be obtained by distillation, but not by the use of a solvent. Geologically oil shale ranges in age from early Paleozoic to late Tertiary. Probably the most extensive deposit of oil shale in the United States is in the Green River formation, of Middle Eocene age, where beds from a few feet to nearly a hundred feet in thickness are found over an area of more than 5500 square miles, in western Wyoming, northwestern Colorado, and eastern Utah. The amount of oil obtained varies from twenty or thirty to sixty or more gallons per ton of shale. At the present time oil-bearing shale is being mined commercially in Scotland and France, but it is hardly yet on a commercial basis in this country, though obviously it is a great potential source of supply that will be more and more utilized as other sources decline.

The above statements naturally suggest a word as to the source or origin of this oil (petroleum), not only that in the oil shale and lignite, but in whatever place it is found. To account for the oil two theories have been proffered, the one that it is of inorganic origin, and the other that it was derived from organic remains, that is, from plants and animals.

It is true that under some rather exceptional conditions, such as occasionally accompany volcanic activities, certain rather complicated chemical reactions take place that may result in the production of petroleum, but the amount produced is infinitesimal and wholly negligible when compared with the vast amount known to exist in nature. This theory is therefore abandoned as an explanation of the source of the principal world supply.

The theory of the organic origin of oil, the view now almost universally accepted, holds that it is a product derived from the decomposition of plant and animal life when under a covering of some sort that prevents the escape of the oils and fats and their loss by volatilization. The petroleum elements may remain to enrich the shale or various types of coal, such as bog-head or cannel-coal, needing only the application of heat to drive it off, as

described above in the distillation of lignites and oil shales. In other cases slow distillation of the organic material results from heat generated by pressure, or movements of the crust of the earth, thus liberating free oil. This free oil may pass into porous rocks or sands that are confined above by impervious layers, and, by gravity or by pressure of water behind or below it, may "migrate" for varying, sometimes long, distances from its actual point of origin, there to accumulate in so-called "pools."

There are, however, two principal groups among the adherents of the organic theory. The first group, which embraces most American petroleum geologists, holds the view that our petroleums are generated from more or less deeply buried organic matter that was subjected to enormous crustal pressure, including the pressure of overlying strata; to incredible pressure due to the contraction of the crust of the earth; and to heat due to depth of burial underground, as well as to chemical action. Generated gases add to the pressure. According to this theory, oil is supposed to have been produced long after the burial of the plant and animal débris.

A smaller group of geologists, represented largely in Great Britain, holds the opinion that oil and other waxy or fatty substances are brought to the sedimentary deposit by the plants and animals at the start, though they may be transformed somewhat and new fatty and oily products may be and by many are supposed actually to be generated in the process of the partial decomposition of the organic débris at the time it is laid down in the sediments. This group holds that the oils thus deposited were formed when the stratum itself was laid down may be altered by the pressure, heat, etc., resulting from the geologic processes already noted, and, in common with the geologists of the other group, agrees that the migration of the oils into the pools occurs at times of buckling and folding of the strata, with sweeping drives of the water content of the rock in directions of least resistance. This readjustment of the water in the strata forces the oil and gas out of the mother rock along with the underground waters. Where the water pressure is high, the oil and gas, being lighter than the water, become eventually separated more or less fully from it, and unless they succeed in escaping to the surface of the earth, they find themselves in the reservoirs, where the oil is underlain

by the water and overlain by the lighter gas, the great pressure of which promotes the yield of our oil fields. The porous rock or reservoir in which the oil is stored is called an oil sand, and for the conservation of oil in this rock it is necessary that the oil sand be capped by clay shales or some other impervious rock.

While the "organic" theory is hardly to be questioned, and while the preponderance of observed facts appears to support that organic theory according to which the oil is generated underground under geologic influences long after its sources are buried in the sediments, it should be remembered that none of these theories has actually been demonstrated to be the one that will account for our natural petroleums. Many factors that enter into the production and accumulation of petroleum, not all of which are yet known, and most of which are too complicated to be further considered here.

We have followed rather hastily the various steps between peat and the several more or less distinct kinds of coal. Is it possible to find out what determines or pre-determines the kind of coal that is to be formed? For instance, it is held by some, especially European students, that the kind of coal depends upon the kind of vegetation of which it is composed, but this view cannot be accepted. As carbon is the essential part of the coal, and as carbon comes from the cellulose of plants, it makes little difference what kind of plants supplied this substance. It has also been suggested that there were differences in the kinds of bacteria by which the plants were decomposed that determined the kind of coal, but this is without convincing proof. The geological age of the coal is thought by some to have an important bearing on the kind and quality of the coal, that is, the older the coal the more nearly does it approach anthracite, which is regarded as the final stage. It is of course true that most of the older, Paleozoic coal has reached the bituminous or anthracite stage, and also that the bulk of the younger coal is in the lignite stage, but it is also found that neither of these distinctions holds good in all cases, for some lignite is found in the Carboniferous, and much bituminous and occasionally anthracite occurs in the Cretaceous and early Tertiary rocks. Evidently some other explanation must be found. The part that heat has played in changing coal from one grade to another, when more or less deeply buried in the earth,

must also be considered. It is well known that when hot volcanic material has been pushed up through a bed of coal, such as bituminous or even lignite, the coal has been changed to anthracite, but this change extends only for a few feet on either side of the intrusive mass. Even when a huge mountain mass of volcanic material has been pushed up through a coal field it is found that the change from low grade coal to anthracite does not extend very far. In some coal fields, as, for example, in the Raton-Mesa field of Colorado and New Mexico, it is thought that the possible presence of a vast sheet or mass of volcanic material beneath the coal—but which never reached the surface—may have changed the coal from one grade to another, but obviously this cannot be proved. A certain amount of heat is present in the earth's crust, and when a coal bed has been deeply buried or when the rocks inclosing it have been folded, faulted, or otherwise disturbed, this heat must have had some effect on the coal in driving off certain gases, and these are steps in changing it from one grade to another, but the extent of this action is not definitely known. Gases of several kinds are present in most, perhaps all, coals but may largely be prevented from escaping by the inclosing rocks. When the coal bed is opened by mining operations the gas may escape and becomes the deadly "black damp" of the miners.

It must be clear to the reader by this time that the study of coal presents many interesting and difficult problems, some of which have been solved with a degree of certainty, while there are others that still require further work and study. The main facts, however, are believed to have been settled with practical certainty. The plant material that entered into the composition of the coal was accumulated in the form of peat, which was changed later into the carbonaceous material we call coal.

Millions of years pass. The crust of the earth grows "restless." The hills, "rock-ribbed and ancient as the sun," are not quite so permanent and unchanging as they seem. A readjustment of the crust takes place—and these changes and readjustments have been happening since the beginning—the downward movement is reversed, and the rocks and coal beds long so deeply buried are elevated, perhaps even thrust upward into mountains. These more or less violent movements in the crust naturally result in certain disturbances in the rocks, and there often is fault-

ing (see p. 14), folding, and crumpling, and in some cases a complete overturning of the rocks.

In some localities, when the coal beds are again brought to or near the surface, the movement has been so slow and gentle that the beds are nearly horizontal, just as they were when first formed, but usually they are now at more or less of an angle, sometimes, indeed, standing nearly on edge. When the beds of coal are flat or nearly so it is often possible to follow them for considerable distances, sometimes for many miles, with little change, but when the crust has been disturbed the coal beds of course show the same disturbances, and one may end abruptly against a blank wall (fault), only to reappear many feet above or below, while others have been crushed and shattered.

Having outlined what is believed to have been the various steps or stages in the formation of coal, we may take as an example the coals of the Carboniferous period in the eastern United States and attempt to reconstruct the conditions that made their formation possible. The Carboniferous, as its name implies, has been called the Age of Coal from the great amount of coal of very great value that was formed at this time.

First we may draw a picture of the probable appearance of the eastern part of the continent at that time. There had evidently been a long quiet period during which the crust was comparatively stable and during which the action of water, wind, etc., had gradually eroded or worn down the rocks, spreading the material in the hollows or depressions and in general reducing the country to a broad, flat plain. This is called base levelling. There may have been mountains during the whole of Carboniferous time, as some geologists hold, but if so there is little evidence of there having been any considerable mountains in or very near the area we are considering. The climate at this time was very mild and equable and extended very uniformly over a large part of the world, even into the Arctic regions, where the same kinds of plants grew that were found in Pennsylvania and central and southern Europe, which of course would be quite impossible under our present climates. There were no frosts and little evidence of climatic change from season to season. There was, however, a very abundant rainfall, and as the country was flat, or nearly so, the drainage was poor or slow—that is, it was a

long time in reaching the ocean. The water collected in the low places, producing a series of vast swamps many square miles in area, and thus the stage was set for the wonderfully luxuriant and varied vegetation that came into being and flourished during Carboniferous time. The conditions were ideal and were not completely duplicated during later geologic time, nor are they exactly duplicated anywhere in the world today.

The great coal swamps of the Carboniferous were very little above sea level. This is shown by the fact that in beds just beneath the coal, as well as in beds of shale or clay between the beds of coal, it is not unusual to find marine shells, but none is found in the coal itself. In the swamps and lagoons that were near the sea the salt or brackish water may occasionally or perhaps regularly have penetrated, and there may have been plants that were able to thrive in such places, but in the majority of cases it is now settled beyond reasonable question that the great swamps were filled with fresh water. None of the descendants or relatives of the plants that made up the rich Carboniferous flora, with the exception of two or three kinds of ferns (*Acrostichum*), are able at the present time to live in salt water or even in soil that contains salt. This is further shown by the fact that certain parasites found on *Stigmaria* ("roots" of *Lepidodendron* and *Sigillaria*), the fungi found in *Lepidodendron* wood, and insects that bored holes in the wood are all fresh-water forms. It is, of course, true that remains of land plants are sometimes found in marine beds, but it can usually be satisfactorily shown that these plants were washed out from the land and are not in the places and under the conditions in which they grew. It is also true that peat is now being formed in many places in salt marshes or inlets covered by salt water at high tide, and there are certain coals that seem to have been formed under some such conditions, but these have been explained by supposing that there were slight elevations never covered by the salt water on which the plants grew and their remains fell into the salt water. Taken by and large, however, it can be confidently stated that a vast majority of the coals of all times and in all places were formed from plants that lived in or near fresh water.

The water was very shallow in these Carboniferous swamps, probably on the average not more than three or four feet in

depth. At the present time peat will not form in water that is much if any over ten feet deep and only slightly then, the most favorable conditions being a depth of four or five feet. Here a mass of roots form and this may gradually extend outward and finally fill up the open water. The conditions must have been similar in the coal swamps, and there was probably little open water. The roots and underground stems are horizontal with various organs or adaptations for bringing them a supply of oxygen. Also some of the trunks were buttressed, that is, enlarged or bulging at the base; some developed adventitious roots, that is, roots springing from various heights on the base of the trunk, as may be seen in the Indian corn; other prostrate parts developed protuberances not unlike the so-called "knees" of the bald cypress of our southern swamps. These are devices for holding the trunks upright in the soft undersoil and the shallow water.

The great swamps were in a region that was very slowly sinking or a broad, shallow basin that was very slowly filling up, or both of these conditions may have been present. If the sinking or filling was slow the water would remain at a more or less constant level, and the formation of peat might continue indefinitely. If the sinking of the crust should suddenly be increased, as it undoubtedly was at times, the vegetation would be drowned, the formation of peat would stop, and a layer of clay or shale might be laid down. Then, if the first conditions were restored, a new crop of plants would grow and the formation of peat would be resumed. If, however, the water level should be lowered or the crust should rise instead of sink, or again, if the filling of the basin should suddenly increase, there might not be sufficient water, and the plant débris, being exposed to the air, would decay instead of going to the formation of peat. These ups and downs and changes in the water level were undoubtedly going on continually, for the results are shown in the coal beds and in the rocks above and below them. A thick bed of coal indicates that the conditions remained stable and little changed for a very long time, while alternating thick and thin beds of coal, or lenses and partings of rock, show clearly that there were changes of one kind or another.

The question is often asked as to the length of time it prob-

ably took in years to form a bed of coal—for example a bed of anthracite, five feet in thickness. It is of course quite impossible to make a reliable estimate for there are so many factors that are unknown, if not indeed unknowable, that about the best that can be done is to show that the time was undoubtedly long, extending into hundreds and more likely, into thousands of years. If, for instance, it requires from ten to twenty feet of peat to make a foot of bituminous coal and there are beds of this coal twenty or thirty or more feet thick, it is plain that a very considerable length of time was required.

Ashley, State Geologist of Pennsylvania, has estimated that old, mature peat is forming in a modern peat-bog at the rate of about one foot per century, and that it requires about three feet of this old peat to make a foot of bituminous coal of the general character of the well-known Pittsburgh coal of Pennsylvania. According to this rate the time required for the formation of the seven feet of this remarkable bed was 2,100 years, or three hundred years to the foot of coal if one foot of peat per century be taken as the average rate of peat formation.

David White, of the United States Geological Survey, in his work on *The Origin of Coal*, ventures the opinion "that if, on the average, one foot of deep peat per century is now forming in the North Temperate bogs, it may not be improbable that a thickness twice as much as that, or perhaps over two feet at the same depth per century may have been deposited in the stagnant waters of the vast forested, lowland swamps of the great coal fields of the Carboniferous; and that most of the widespread peat of the Mesozoic and Tertiary was probably laid down one-half faster than the average recent peat of Europe, Canada, and the United States."

A German student has estimated that a coal bed from twenty to thirty feet in thickness and covering an area of six hundred square miles in China would have required more than four hundred feet of plant material if it were grown in place.

The estimates of other writers could be quoted, but they would only serve to emphasize the fact that the time was undoubtedly long, though perhaps not accurately measurable in years.

Another question frequently raised and one of far more importance to civilization and human progress is: How long is

the supply of coal likely to continue? Many estimates have been made, mostly ranging from one hundred to a thousand years, with the truth perhaps somewhere between. But there are so many and such varied factors that must be taken under consideration that it is difficult, if not indeed impossible, to reach a wholly reliable conclusion. Naturally the high-grade Paleozoic coals will first be drawn on. Beds of these coals too thin to be profitably mined at the present time will doubtless be opened up. Then the lower grade coals, such as the lignites and sub-bituminous coals of which there are vast quantities in our Rocky Mountain and adjacent States, will be utilized, and coal resources not fully known or even prospected—in Alaska, China, and elsewhere—must sooner or later be brought into use. Again, the constantly increasing use of electricity produced by water-power—the so-called "white coal"—and the use of fuel oil will all tend to some extent to reduce the consumption of coal and thus conserve the supply. It should not be lost sight of, however, that all increases in the development of power seem to stimulate increased uses for manufacturing and other purposes, all of which makes it increasingly difficult to "guess" as to the length of time the supply will last. But the fact remains that there is a possible end of our coal resources sometime in the not very distant future, and hence all reasonable steps should be taken to reduce preventable waste and thus prolong the supply as long as possible, for the future of civilization is largely bound up with it.

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